MEMBER OF THE AUDIT BUREAU OF CIRCULATIONS

A TECHNICAL JOURNAL FOR DESIGNERS AND USERS OF ELECTRICAL, ELECTRONIC, HYDRAULIC, MECHANICAL AND PNEUMATIC CONTROL SYSTEMS AND INSTRUMENTATION

VOL 4 NO 39 SEPTEMBER 1961

CONTROL

SYSTEMS · INSTRUMENTATION · DATA PROCESSING · ENGINEERING · APPLICATIONS

SPECIAL FEATURES

REGULAR FEATURES

LOOKING FOR A JOB? Control *carries the best jobs in instrument and control engineering.* **SEE PAGE 194 AND ONWARDS**

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LOOKING AHEAD

Unless otherwise indicated, all events take place in London. B.C.A.C., British Conference on Automation and Computation. B.C.S., British Computer Society. Brit.I.R.E., British Institution of Radio Engineers. I.C.E., Institution of Civil Engineers. I.Chem.E., Institution of Chemical Engineers. I.E.E., Institution of Electrical Engineers. I.Mech.E., Institution of Mechanical Engineers. I.Prod.E., Institution of Production Engineers. I.S.A., Instrument Society of America. R.Ae.S., Royal Aeronautical Society. S.B.A.C., Society of British Aircraft Constructors. S.I.T., Society of Instrument Technology.

SUNDAY 3—TUESDAY 12 SEPTEMBER
European Machine Tool Exhibition. Brussels. Details: Commissariat Général de la 7e Exposition Europeéne de la Machine-Autil, 13 rue des Drapiers, Bruxelles 5, Belgium; and Machine Tool Trades Association, Brettenham Ho., Lancaster Place, W.C.2.

MONDAY 4—FRIDAY 8 SEPTEMBER
Rutherford Jubilee International Conference. Details: L. J. B. Goldfarb, Physics Dept, University of Manchester, Manchester, Lancs.

MONDAY 4—SATURDAY 9 SEPTEMBER
3rd International Session of the International Association for Analogue Computation. Belgrade, Yugoslavia. Details: Yugoslav Committee for Etan, Terazije, 23/VII, Belgrade, Yugoslavia.

MONDAY 4—SUNDAY 10 SEPTEMBER
S.B.A.C. Flying Display and Exhibition. Farnborough. Details: S.B.A.C., 29 King St, St James's, London, S.W.1.

TUESDAY 5—FRIDAY 8 SEPTEMBER
An international conference on *Machine translation of language and applied language analysis.* National Physical Laboratory, Teddington, Middlesex. Papers to Dr A. M. Uttley, Autonomics Div., N.P.L.

National Inspection Conference (jointly with National Committee on Non-destructive Testing). New College, Oxford. Details: Institution of Engineering Inspection, Grand Bldgs, 616 Trafalgar Sq., London, W.C.2.

WEDNESDAY 6—FRIDAY 8 SEPTEMBER
International Symposium on *Transmission and processing of information.* Massachusetts Institute of Technology. Submission of papers is invited. Details: R. M. Fano, R.L.E., M.I.T., Cambridge, 39, Mass., U.S.A.

Joint Nuclear Instrumentation Symposium. North Carolina State College, Raleigh, N.C., U.S.A. Sponsors: I.S.A., A.I.E.E., I.R.E. Details: Meetings Manager, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

MONDAY 11—THURSDAY 19 SEPTEMBER
20th International Congress of Navigation. Baltimore. Details: Permanent International Association of Navigation Congresses, 60 rue Juste Lipse, Brussels, Belgium.

MONDAY 11—WEDNESDAY 13 SEPTEMBER
Fifth International Congress of the European Organization for Quality Control. Turin, Italy. Details: European Organization for Quality Control, Weena 700, Rotterdam, Holland.

MONDAY 11—FRIDAY 15 SEPTEMBER
I.S.A. Instrument-Automation Conference and Exhibition and I.S.A.'s 16th Annual Meeting. Memorial Sports Arena, Los Angeles, Calif., U.S.A. Details: Wm H. Kushnick, I.S.A., 313 Sixth Av., Pittsburgh, 22, Pa, U.S.A.

Third International Congress on *Cybernetics.* Namur, Belgium. Details: Association Internationale de Cybernétique, 13 rue Basse-Marcelle, Namur, Belgium.

MONDAY 18—FRIDAY 22 SEPTEMBER
Symposium on *Network theory.* Cranfield. Details: S.R. Deards, Department of Electrical and Control Engineering, The College of Aeronautics, Cranfield, Bletchley, Bucks.

MONDAY 25—FRIDAY 29 SEPTEMBER
2nd International Machine Tool Design and Research Conference. Manchester. Details: J. P. Mabon, Royce Laboratory, Manchester College of Science and Technology, Sackville St, Manchester 1.

TUESDAY 26 SEPTEMBER
Underground gasification of coal—some features of instrumentation by Dr A. E. Balfour, and *Trends in mining instrumentation* by A. E. Bennett. 6.30 p.m. for 7 p.m. Manson Ho., 26 Portland Pl., W.1. (*S.I.T.*)

TUESDAY 26 SEPTEMBER—FRIDAY 6 OCTOBER
International Heating, Ventilating and Air-conditioning Exhibition. Olympia. (A conference will run concurrently from Wednesday 27 September — Wednesday 4 October.) Sponsors: Institution of Heating and Ventilating Engineers.

WEDNESDAY 27 SEPTEMBER
First B.C.A.C. annual lecture. *Mathematics—Friend of Foe?* by Dr D. G. Christopherson. Lecture Theatre, I.E.E. Details: B.C.A.C. c/o I.E.E.

MONDAY 2—FRIDAY 6 OCTOBER
International Astronautical Federation Congress. Washington, D.C. Details: The British Interplanatary Society, 12 Bessborough Gdns, Lonson S.W.1.

MONDAY 2—WEDNESDAY 11 OCTOBER
Business Efficiency Exhibition, Olympia. Details: Hart-Lidbury, Panton Ho., 25 Haymarket, S.W.1.

WEDNESDAY 4—THURSDAY 12 OCTOBER
Second Electronic Computer Exhibition and Symposium, London. Details: Mrs S. S. Elliott, 64 Cannon St, E.C.4.

THURSDAY 5—FRIDAY 6 OCTOBER
Two-day export conference. Details: C. G. E. Parrot, Overseas Div., B.E.A.M.A., 36 Kingsway, W.C.2.

SUNDAY 15—THURSDAY 19 OCTOBER
16th Engineering Conference (T.A.P.P.I.). Washington, D.C. Details: Technical Association of the Pulp and Paper Industry, 155 East 44th St, New York, 16, U.S.A.

THURSDAY 19 OCTOBER
The Thomson Lecture: *The inspiration of science,* by Sir George Thomson at 6 p.m. at The Royal Institution. Admission by ticket only. (*S.I.T.*)

THURSDAY 19—FRIDAY 20 OCTOBER
A symposium on *Scale-up and pilot plants.* The Royal Overseas League, St James's, S.W.1. (*I.Chem.E.*)

TUESDAY 24—THURSDAY 26 OCTOBER
National Conference of the British Institute of Management. Details: Miss E. Ellett, 80 Fetter Lane, E.C.4.

TUESDAY 31 OCTOBER—FRIDAY 3 NOVEMBER
Effluent and Water Treatment Exhibition and Convention. Seymour Hall. Details: P. I. Craddock, Dale Reynolds Publicity, 2 Broad Street Place, E.C.2.

WEDNESDAY 1 NOVEMBER
Annual dinner of the I.Prod.E. Dorchester Hotel. Principal speaker will be The Rt. Hon. Viscount Chandos. (*I.Prod.E.*).

WEDNESDAY 8—FRIDAY 10 NOVEMBER
Conference on *Non-destructive testing in electrical engineering.* (*I.E.E.*)

MONDAY 13—SATURDAY 18 NOVEMBER
Second Engineering Materials and Design Exhibition and Conference. Earls Court. Details: J. Brewster, Commonwealth Ho., New Oxford St, W.C.1.

International Factory Equipment Exhibition. Earls Court. Details: J. Brewster, Commonwealth Ho., New Oxford St, W.C.1.

WEDNESDAY 22 NOVEMBER
A symposium on *Materials in space technology.* The Lecture Theatre, R.Ae.S. Details: The British Interplanatary Society, 12 Bessborough Gdns, S.W.1.

LOOKING FURTHER AHEAD

WEDNESDAY 17—THURSDAY 18 JANUARY 1962
A symposium on *Electronic aids to banking,* under the aegis of B.C.A.C. Details: I.E.E.

MONDAY 22 JANUARY 1962
'Exposition meeting' on *Recent developments in automatic boiler control practice.* Details: R. J. Redding, 66 The Drive, Isleworth, Mddx. (*See also Control, July, p.* 122). (*S.I.T.*)

FRIDAY 16—TUESDAY 20 FEBRUARY 1962
Salon Internationale des Composants Electroniques. Parc des Expositions, Porte de Versailles. Details: S.D.S.A., 23 rue de Lubeck, Paris 16e, France.

APRIL 1962
'Exposition meeting' on *Self adaptive control systems.* Details and suggestions: R. H. Tizard, Whitterick, Ellesmere Rd, Weybridge, Surrey (*See also Control, July, p.* 122). (*S.I.T.*)

WEDNESDAY 25 APRIL—FRIDAY 4 MAY 1962
Conference Internationale des Arts Chimique. Paris. Details: Maison de la Chimique, 28 bis rue Saint-Dominique, Paris 7e, France.

MONDAY 30 APRIL—FRIDAY 4 MAY 1962
Second International Compressed Air and Hydraulics Exhibition. Olympia. Details: W. G. H. Chesher, St Richard's Ho., Eversholt St, N.W.1.

TUESDAY 8—FRIDAY 18 MAY 1962
Mechanical Handling Exhibition. Earls Court. Details: H. A. Collman, Dorset Ho., Stamford St, S.E.1.

THURSDAY 31 MAY—THURSDAY 7 JUNE 1962
International Television Conference. Institution building, London. (*I.E.E.*).

WEDNESDAY 20—TUESDAY 26 JUNE 1962
Third Congress of the European Federation of Chemical Engineering. Olympia. Details: The General Secretary, Society of Chemical Industry, 14 Belgrave Sq., S.W.1.

MONDAY 16—FRIDAY 20 JULY, 1962
International conference on *The physics of semiconductors.* Exeter University. Details: The Administration Assistant, The Institute of Physics and The Physical Society, 47 Belgrave Sq., London, S.W.1.

TUESDAY 14—THURSDAY 16 AUGUST 1962
Conference on *Standards and electronic measurements.* Boulder Laboratories of the National Bureau of Standards. Details: J. M. Richardson, Radio Standards Laboratory, National Bureau of Standards, Boulder, Colo., U.S.A.

THURSDAY 15—TUESDAY 20 OCTOBER 1962
International Congress and Exhibition of Laboratory, Measurement and Automation Techniques in Chemistry (Ilmac). Swiss Industries Fair, Basle, Switzerland. Details: M. Trottmann, Foire Suisse, d'Echantillons Basle, Switzerland.

MONDAY 1—FRIDAY 5 JULY 1963
3rd Conference, International Federation of Operational Research Societies. Oslo University, Norway. Enquiries: Sir Charles Goodeve, International Federation of Operational Research Societies, 11 Park Lane, London, W.1.

SEPTEMBER 1963
Second congress of the International Federation of Automatic Control. (Ifac). Basle, Switzerland. Details: papers, B.C.A.C., c/o I.E.E.; general inquiries, Dr-Ing. G. Ruppel, Prinz-Georg-Strasse 79, Düsseldorf, Germany.

SEPTEMBER 1961 VOL. 4 NO. 39

CONTROL

An age of mergers

BRITISH INDUSTRY FINDS it very hard to believe that the word 'automation' means anything new. It is admittedly a name for an extension of processes that have been going on for a long time, but there are contributions which are evidently unique to our own day, and these are important enough to justify a new term. The old word, 'mechanization', suggested the introduction of machinery considered as gears, cranks, rods, levers, belts, chains etc. The modern word makes clear that control and systems engineers are not restricted to the governing methods of Watt, though unfortunately some people have gone too far and have identified it exclusively with the most recent electrical methods.

Engineers, like many other men, are often reluctant to break loose from the anchorages of their youth, and those who were trained as mechanical or electrical engineers still tend to regard either the mechanical or the electrical particularities as the fundamental ground of automation. There are mechanical engineers who shun 'delicate' electronics, and who have instrumentation draped onto their plant as an afterthought: and there are electrical engineers who so dote on electromagnetics that they are blind to the advantages of electrohydraulics. Only very recently we heard a pundit declare that all automatic control is electrical underneath. He admitted that pneumatic controllers run on compressed air, but he dismissed that as a quibble because the compressors are driven by electric motors! A partisan on the other side might have counter-claimed primacy, since mechanical engineers are still responsible for the prime movers.

There is little squabbling of this sort among the new generation of control engineers. They accept without question the monthly implication on our title page that electrical, electronic, hydraulic, mechanical and pneumatic techniques all flow together into control engineering. Sadly, this new generation still has very little say in the formulation of policy. It does not even have a body to represent it professionally. Yet the established institutions have linked themselves in the British Conference on Automation and Computation, and while that Conference, as such, has no qualifying status, it does show that the engineering profession is at least aware of certain greater technological trends. Industry, on the other hand, remains largely unconvinced. Here and there, it is true, there are companies that sell automation entire, that recognize the importance of the systems approach: but generally speaking the supplying firms are every bit as parochial as the old-fashioned 'mechanical' and 'electrical' engineers—they stick to their components, instruments and machines, and do not venture very far in devising an architecture for these building bricks. To an extent this is because users will rarely entrust the automation of their plants to existing suppliers. In many (if not most) cases it is probably right for the users to do the job themselves, but there are some openings, and perhaps too little has been done to win the confidence of wary British directors and managers.

One of the more acceptable definitions of 'automation' is that it is the confluence of three technological streams: automatic machining, processing and manipulation; automatic control of quality and quantity; and automatic data handling. Where is the trade association to represent this confluence? We know that there are associations doing excellent work in channelling the single streams or pairs of them, but the time has now come for one strong group to contain automation as a whole. This is an age of mergers and confederations. If all goes well, the United Kingdom will soon be in the European Economic Community. Big trading possibilities in a united Europe will call an ever mightier challenge to the suppliers of industry, and British manufacturers will have to make a big and united effort to meet it.

LETTERS *to the EDITOR*

Pounds and pounds

SIR: Once more I sit pen-in-hand, tongue-in-cheek to reply to Mr. Helmer. (*Letters*, July, p. 86.) I shall commence by considering the specific points he mentioned.

1. The slug is chosen so that the unit of mass is compatible with the units of length and time—after all, why should the size of our planet be dragged in as well?

2. I am sure that Mr. Helmer would be very surprised at the number of engineers who seem to consider "g" as something sent to trouble us rather than as a simple acceleration; for example, if the local value of "g" differs from 32.2ft/s², they wonder if one divides by "g"-local to convert from pounds to slugs. My remarks concerning the nature of "g" were intended to help these unfortunates and were not directed at those who knew about "g" *even before they went to college*.

3. I did not say that the Stroud system gives the wrong answer for specific impulse. "Cancelling" pounds mass with pounds force gives the impression that specific impulse has the units of time. The consequences of not knowing that someone has performed this or a similar "cancellation" may well be disastrous when converting from their system of units to the one in use at the time.

In his original letter (*Letters*, February, p. 83) Mr. Helmer dismisses the poundal and the slug in a few words on the grounds that "neither really exists", then, when I point out the advantages of using the slug in particular he immediately accuses me of "adopting the slug to the exclusion of other units". This is most unfair. Perhaps Mr. Helmer will feel happier if I express only a "strong preference" for the slug, foot, second system, or perhaps he detects an unwillingness on my part to adopt the Stroud system to the exclusion of others!

To return to fundamentals, Ohm teaches us that a potential difference produces a current flow. For this reason, a generator is often considered as a voltage source with a series impedance; however, one can equally well consider a generator as a current source with a shunt admittance. Is Mr. Helmer going to dismiss the concept of a current source because he cannot find the voltage that produces the current? We find that it is not the force, but the *acceleration* due to gravity which is independent of the mass of a body, and thus gravity appears as an "acceleration" source. Placing a mass in a gravitational field is synonymous with placing a resistor in circuit with a current source; the resulting force on the mass is synonymous with the voltage across the resistor. (I apologize to Mr. Peterson* for referring to an acceleration as "acting" on a body, but could think of no better term to use.)

Finally, I still maintain that the best system for an engineer to use is the one he understands best. I therefore recommend Mr. Helmer to stick to the Stroud system (bless him). J. B. HARGRAVE
English Electric Aviation Ltd

SIR: It really is quite absurd that your correspondents should argue with Mr. Helmer over the question of units, except in as much as he is a devotee of Stroud. There are now international standards in this matter and all is crystal clear in B.S. 350 Part I: 1959 and B.S. 1991 Part I: 1954 as amended by Amendment No. 3 of 4th October, 1960. These standards do not tie down English-speaking engineers and scientists to any group of units or to any system and the "g" bogy is gone for ever.

What is so unfortunate is that so many old and some new textbooks have been written by people who have not taken the trouble to make an elementary study of units. In the more enlightened texts, where a physical phenomenon depends on gravity, the symbol g appears in the theoretical analysis—*otherwise it does not so appear*. In how many texts can one read, for example, kinetic energy expressed as $v^2/2g$, despite the fact that kinetic energy has not the remotest connection with gravity? When the calculation of a *problem* is involved, it *may* be necessary to insert a conversion factor in order to balance the units chosen but this is none of the business of the formal analysis. The same mistake is often made with J, the so-called Joule's equivalent; this is just another unit conversion factor and has no place in the theory.

Since the "32·2" problem has been discussed at length, may I state quite simply that in problems *not* involving gravity, all one needs to remember is that 1 pdl is *defined* as $1 \text{ lb} \times 1 \text{ ft/s}^2$. If one wants to work in lbf instead of pdl for force, the relation between the two units is now *exactly* specified by 980·665/30·48 pdl/lbf which works out at 32·2 pdl/lbf to three significant figures. If one wants to use slug instead of lb for mass, exactly the same specified factor is involved. Clearly, if one works in lbf *and* in slug, there is no need for the 32·2, any more than there is when working in pdl and lb.

Where gravitational acceleration affects a problem *on earth*, it is necessary to insert g in the analysis and to substitute for it by roughly 32·2 when measured in ft/s² or by other numbers where other units are used.

No difficulty can possibly arise over problems sited away from the earth's gravitational field; here the appropriate value of g is used if it *is* a problem affected by gravity, but otherwise our friend 32·2 may still appear unaltered where it is merely a conversion factor. C. R. WEBB
Queen Mary College, London

● Uncontrolled *writes: 'Amendment 3 of BS 1991 was the cause of all this correspondence (see* Pick-off, *Dec., 1960, p. 124)—so much for crystal clarity!'* Uncontrolled *makes some further comments in* Pick-off *this month.*—EDITOR

* *Letters*, July 1961, p. 86.—EDITOR

VIEWPOINT

A. Normand Provost, Managing Director of Texas Instruments, suggests that we may have something to learn from the Americans about . . .

CONTROL AND RELIABILITY

The terms *closed loop, open loop, feedback, attenuation, amplification,* and so forth, are well known in the descriptive terminology applied to control systems, and because control systems without the application of the principles implied by these terms would be ineffective, most engineers accept and discuss them readily and easily.

Examples of what is expressed in the basic control concepts have existed since man began—systems of warning devices of one type or another, with the element of man closing the loop. Throughout history, there has been a distinct emphasis, perhaps intuitive at times, on making these control systems more effective. In place of the term 'effective', I might easily put 'reliable'. As control systems became more and more sophisticated, even greater emphasis was placed upon reliability, although in many instances any advance in reliability was considered satisfactory if it could replace one additional element of human effort or judgement. But without the underlying philosophy, knowledge, and understanding of control systems, progress was at best extremely slow and time-consuming; at worst, the intended improvement was no better than that supplied by the previous human action. However, in recent years there has been an increasing emphasis on reliability.

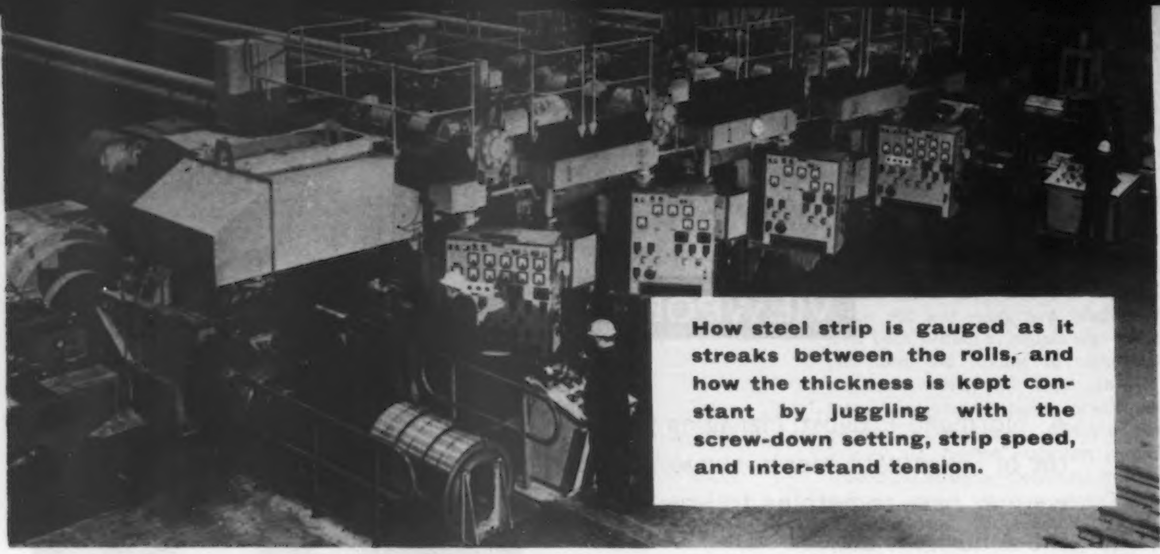
On various occasions I have been asked to comment on the differences between American and British industry and science. In answer, I have noted that the British scientist or engineer tends to have a more sophisticated, or a more fundamental, appreciation of the philosophies of the problem under consideration. Yet, oddly enough, in the field of reliability, the one area where this might have been expected to be particularly pronounced, I have found it less so.

The basic concepts of statistical quality control as practised in the United States rest firmly upon many of the basic studies originally developed in Britain. In its simplest terms, *quality* may be expressed as a definitive description of the condition of the product or process at a point in time, whereas *reliability* is a definitive description of a product's or process's ability to maintain its condition in time. It would be expected that understanding of the basic concepts, practices and necessity of reliability would be as sophisticated as, if not more than, in the States; the fact that this is not so strikes me as most odd. It is a general truth that the industries most concerned with reliability have been those engaged in electronics, and among these much of the latest thinking has come from those engaged in the manufacture and application of semiconductors. We feel the element of reliability, after a description of the performance characteristics of a device or system, to be one of the next most important statements concerning that device or system.

Certainly, when one thinks of the reliance being placed upon control systems and their applications to more and more exacting tasks, tasks which affect human life and performance more and more directly, there can be but little question that we must continue and even accelerate our present efforts if we are to gain the most from our relatively recent advances in science and engineering.

For these and other reasons, both manufacturers and users of semiconductors are acquiring more and more information on the reliability of semiconductors as individual components and as part of a system. Increasingly one sees specifications being drawn up on test conditions simulating *both* maximum performance requirements. Under normal testing conditions, it may take years to develop probability statements concerning reliability, although recent advances in step-stress techniques indicate distinct possibilities for reducing these time-consuming researches. In addition, the application of the basic concepts of control to the total conditions of product processing have been found to be of vital importance in assuring the reliability necessary in the component, if the end product is to have the required element of reliability.

Thus, it is only by introducing the basic elements of control practice into the smallest process element, and in bringing together philosophy and practice more completely, that the final reliability of the overall control system will be positively assured.



How steel strip is gauged as it streaks between the rolls, and how the thickness is kept constant by juggling with the screw-down setting, strip speed, and inter-stand tension.

Control of a modern cold rolling mill

by **J. C. SMITH** *and* **I. C. ROSS**, *Steel, Peech & Tozer*

A MODERN COLD ROLLING MILL IS A COMPLEX PIECE OF equipment in which instrumentation and automatic control play an important part in the production of high-quality steel strip at maximum speeds. Three parameters, strip tension, mill speed and automatic 'gauge' (i.e. thickness) control are complementary in forming a vital part of the mill control system. In this article the method of control used on the recently-commissioned four-stand tandem mill at the Steel, Peech and Tozer Branch of The United Steel Companies is outlined. The above heading illustration shows a general view the mill.

GENERAL PLANT LAYOUT

Raw material for cold rolling is supplied from a continuous hot strip mill. After pickling to remove scale, the strip is delivered to the cold rolling department in coils.

The strip is reduced primarily in a four-stand,* four-high† mill. Feeding and stripping of the mill is entirely mechanized, and strip between 18in × 0·250in and 6in × 0·048in can be handled with equal facility.

During cold rolling the steel is considerably work-hardened and it is then necessary to anneal. There are two continuous annealing furnaces, heated by radiant tube burners fired with coke-oven gas.

After annealing, the coils are transferred to the two-high temper mill, where the strip is slightly reduced in thickness to produce the temper and surface finish required by the customer. Finishes varying from matt to mirror can be imparted to the strip at this stage.

* Each assembly of rolls, together with supporting framework and ancillaries, is called a *stand*.

† The number of rolls mounted above each other is the 'height' of the stand. If there are two small-diameter rolls (' work rolls ') actually nipping the strip, and each of these is supported by large-diameter (' back-up ') rolls to give rigidity, the stand is called *four-high*.

THE MILL

Thickness is decreased, and length consequently increased, in a cold rolling mill by plastic deformation of the strip in the roll gap under the heavy load. The thickness or 'gauge' of the strip leaving the rolls is also influenced by tension. An increase in tension decreases strip thickness, and *vice versa*. The influence of tension decreases rapidly with increasing thickness. When combined with screw-down control, however, variable tension provides an effective way of obtaining fine control of gauge inside the screw-down control range.

In a tandem mill the strip is progressively reduced in thickness without intermediate coiling. Fig. 2 shows the schematic arrangement of a four-stand four-high mill.

The strip is not in contact with guides of any description during rolling, and is kept central in the mill by inter-stand tension. This tension is infinitely variable over the working range. Any deviation from straightness is indicated on the panels attached to each stand, enabling the operator to ensure production within very close limits of straightness.

The mill is of the most advanced design. The first and fourth stands are equipped with automatic gauge control, while there is automatic control of tension between the third and fourth stands. The electrical plant embodies many of the latest techniques in rolling mill control. The mill motors are supplied from rectifier inverter units during both acceleration and steady running of the mill, and they accept regenerated power during deceleration. This type of cold-rolling mill drive is believed to be unique in this country.

The electrical plant is supervised overall from a central control desk, from which the main a.c. breakers

are controlled, and into which is built the bulk of the instrumentation for the main drives and their associated power equipment. The attention of maintenance personnel is immediately drawn to any fault during rolling by an audible alarm, and a flashing annunciator gives the location and type of fault.

POWER EQUIPMENT

Power equipment for the main drive motors consists of transformer-fed steel-tank mercury-arc rectifier/inverter units, the transformers for which have double secondary windings for rectifier and inverter duty respectively.

Two grid-controlled, six-anode steel-tank converters are connected as rectifiers to supply the stand motor, and a single tank is connected as an inverter to accept regenerated power. The arrangement for the coiler motor is similar, except that only a single tank is used for rectifier duty.

The uncoiler converter equipment comprises single-anode excitron tubes supplied at 415V.

Main drives

DRIVE	OUTPUT	SPEED RANGE rev/min	ROLL ft/min	MAX. DRAFT %
Uncoiler	25kW	250/880	—	—
Stand 1	1000hp	168/476	460/1200	44
Stand 2	1000hp	212/551	580/1510	41
Stand 3	1000hp	241/627	660/1715	31
Stand 4	1000hp	291/764	800/2100	28
Coiler	300hp	126/440	—	—

The mill motors are continuously rated, shunt-wound, separately excited machines operating on the Ward Leonard principle. The maximum motor terminal p.d. for the stand drives is 600V d.c., this being the optimum value for mercury arc converters and motors such as those installed.

The uncoiler and coiler motors operate at 350V d.c., and are electrically coupled to speed reference exciters driven by the adjacent mill motor.

The uncoiler motor, which acts as a drag generator during rolling, has a speed range of 3 : 1 under field control to compensate for the reduction of coil diameter which takes place during the rolling operation.

The coiler motor also has the field range required for the build-up of the coil.

CONTROL REQUIREMENTS

As variation of tension produces a variation in gauge of the rolled product, it is essential that tension developed in all sections of the strip be kept as nearly as possible constant throughout the pass, this regardless of the particular rolling speed, of whether the mill is accelerating or decelerating, and of coil diameter.

Three systems of tension control are incorporated, and will be described below.

The coiler

Control of strip tension between the coiler and the last stand is obtained by controlling the armature current and voltage of the coiler motor, so that predetermined power is applied to the strip. If the tension required is T lbf and the linear speed of the strip is N ft/min, the horsepower developed in the strip is $NT/33{,}000$. If the coiler motor armature current is I amperes at voltage V, the horsepower developed is $VI/746$.

Equating these two powers, $NT/33{,}000 = VI/746$ and $T = 44{\cdot}3(V/N)I$. As the armature voltage V approximates the back e.m.f. of the motor, which is proportional to speed, $T \propto I$ approximately.

Tension T is thus proportional to the coiler motor's armature current, and if by progressive strengthening of the motor field current the motor's back e.m.f. is held constant for a particular strip speed, the tension will be kept constant over the whole range of coil diameter.

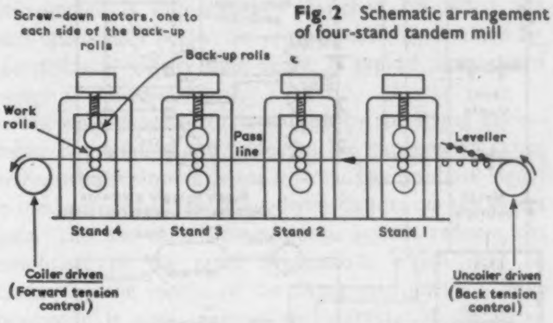


Fig. 2 Schematic arrangement of four-stand tandem mill

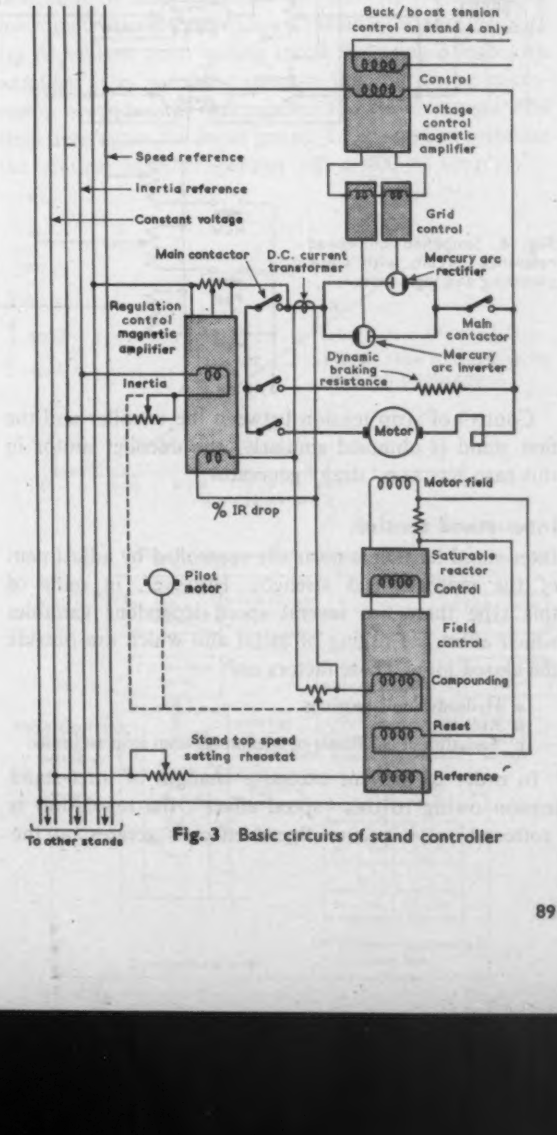


Fig. 3 Basic circuits of stand controller

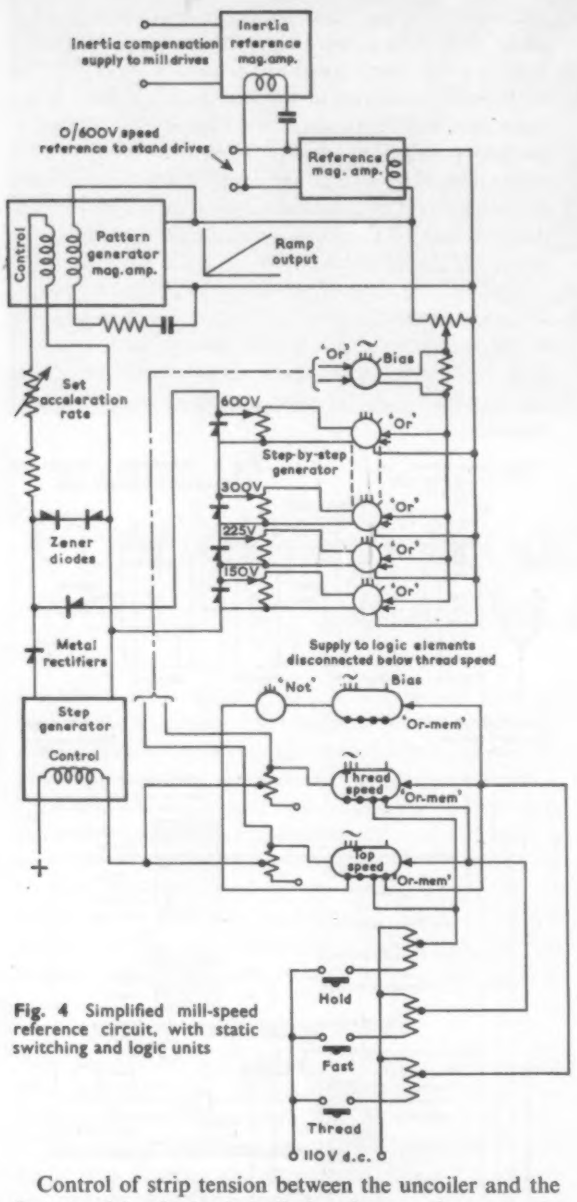


Fig. 4 Simplified mill-speed reference circuit, with static switching and logic units

Control of strip tension between the uncoiler and the first stand is obtained similarly; the uncoiler motor in this case acts as a 'drag' generator.

Inter-stand tension

Inter-stand tension is normally controlled by adjustment of the motor's field strength. However, in mills of this type there are several speed-dependent variables which affect the rolling of metal and which are outside the closed loop. These factors are:

- **a** Hydrodynamic bearings
- **b** Roll distortion
- **c** Variation of coefficient of friction between strip and rolls.

In order to prevent excessive changes of inter-stand tension owing to this 'speed effect', the regulation is 'softened' as it occurs. Speed effect is greatest at the third and fourth stands, and for this reason control of tension between these stands is included in the system.

A closed-loop tension-control system is used between the third and fourth stands. The tension reference is obtained from the *Set Tension* rheostat, set by the operator. The reset signal is obtained from a tensionmeter situated between the third and fourth stands. The tensionmeter consists of a spring-loaded roller in contact with the strip, and moves vertically in sympathy with changes of strip tension. Movement of the roll causes movement of the armature of a linear variable differential transformer, the output from which is rectified and fed into the reset winding of the tension mag.-amp.

Tension error is corrected by a change of rectifier output voltage by grid control.

When gauge is being automatically controlled, an additional tension mag.-amp. winding is supplied from the automatic gauge control ('a.g.c.') circuits to buck or boost the tension reference by 20%. If correction of gauge error is outside the range of tension control, the roll gap is adjusted by screw-down operation.

Strip tension is kept constant under all rolling conditions by modification of the tension reference signals to compensate for inertia, *IR* loss, speed losses, etc.

The basic circuit of stand drive control is shown in Fig. 3.

SPEED

Fig. 4 shows the basic circuitry of the mill speed reference equipment. Magnetic-type static switching units perform the logic functions initiated by the mill operator to provide the speed reference signal to the mill.

The mill is brought to 'thread' speed from rest, for the nose end of the strip to be fed into each stand. When several laps have been taken up by the coiler mandrel the mill is accelerated by depression of the *Fast* push-button. Any one of several speeds intermediate between thread speed and the top speed setting can be obtained by pressing the *Hold* button.

A signal representing the required speed is fed into the 'step generator' which feeds a step input into the 'pattern generator', from which a ramp output is obtained as shown in Fig. 5. Operation of the *Hold* push-button removes the 'step generator' output, the 'pattern generator' reference then being obtained from the 'step-by-step' generator, the output from which is determined by the level that was reached by the 'pattern generator' output before the *Hold* button was operated.

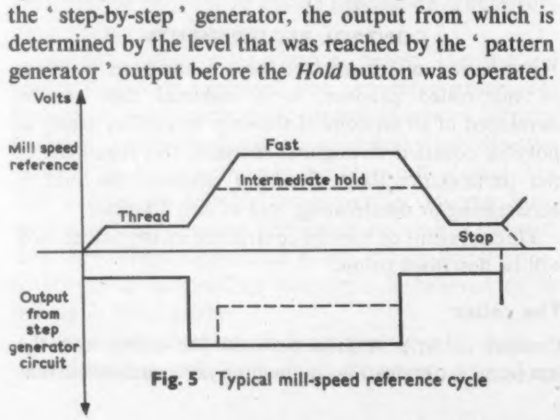


Fig. 5 Typical mill-speed reference cycle

The mill is decelerated by operating the *Thread* push-button, which causes the removal of the signal from the ' step-by-step ' generator.

AUTOMATIC GAUGE CONTROL

Detailed research into the causes of gauge variation in flat rolled products has been carried out in the laboratories of The British Iron and Steel Research Association. As a result, a new approach to automatic gauge control was stated in a paper by Hessenberg and Sims (*1*). This work led to the error-sensing system known as the gaugemeter (*2, 3*). The system has been developed commercially by the Davy & United Engineering Co., whose Instrument Division supplied the gauge control equipment for the Steel, Peech and Tozer mill.

The gaugemeter

When a cold rolling mill is loaded it behaves as a spring. The spring rate, or stiffness, is known as the ' mill modulus ' M. It is the change in roll load per unit change in roll gap, and it can be determined practically by bringing the rolls into contact without strip in the gap and recording the screw settings and the mill load. A typical characteristic is shown in Fig. 6; the gradient of the linear part of the curve represents the value of M. Since the critical load is usually less than the normal rolling load the general equation relating rolling load F and strip thickness h will be

$$F = M(h - S_0) \qquad (1)$$

where S_0 is the initial roll gap before load is applied. Hence

$$h = F/M + S_0 \qquad (2)$$

Should the rolling load become less than the critical load, then the non-linear characteristic can be taken out with a non-linear element, e.g. a tapped potentiometer.

The rolling load F is measured with strain-gauge load cells under each of the motor-driven screws which apply the rolling force. The initial setting of the roll gap is determined by screw-down synchros.

This system of measurement has the advantage that the strip is gauged and rolled simultaneously, eliminating the distance/velocity lag associated with an installation using a thickness gauge mounted on the exit side of the mill. The control system is therefore stable down to zero mill speed.

Screw-down control

The gaugemeter gives an electrical signal proportional to the thickness of the strip in the roll gap. Another signal is obtained from a ' set thickness ' control and the two signals are compared. An error signal is now used to control the action of the screw-down motors so that the gauge error is reduced.

Screw-down control is on–off in nature, and the limits must be predetermined. This setting, the ' screw-down gate ', is manually selected by the roller at 0·001in, 0·0005in or 0·0003in. Since the gaugemeter uses information derived from the roll gap, any roll eccentricity will produce a cyclic signal from the error detection circuit. It is impossible to ensure that the rolls in a four-high stack are ground and assembled without any eccentricity whatever, so the correct setting of the gate switch also prevents cyclic operation of the mill screws.

The gaugemeter is naturally affected by changes in the work-roll and back-up-roll diameters owing to changes in roll temperature during rolling. As the thermal inertia of the rolls is high, changes in roll diameter are slow relative to the response of the gaugemeter. Gaugemeter drift can therefore be corrected by using a thickness gauge on the outgoing side of the mill. The thickness gauge thus acts as an overall monitor of control system performance.

A downstream contacting instrument, which is known as the flying micrometer, is used to provide the error signal that automatically adjusts the gaugemeter signal. To avoid instability at low speeds, the flying micrometer is automatically switched off when the mill speed falls below the critical value determined by the distance/velocity time delay. A typical screw-down system is shown in Fig. 7.

The true gauge error measured by the flying micrometer is amplified and added to the gaugemeter gauge error, using a slow-response system. The resultant signal is used to operate the screw-down motors *via* the preset gate. The use of a slow-response system reduces the amplitude of the rapid fluctuations which may be caused by the inertia of the flying micrometer (' mike bounce '). It also increases the stability of the flying micrometer circuit, which has a variable distance/velocity lag dependent upon rolling speed. By using a high-gain amplifier it is possible to ensure that the flying micrometer overrides the gaugemeter for slow changes and thus determines the mean gauge. To ensure fast response the control system operates off a 400 c/s supply.

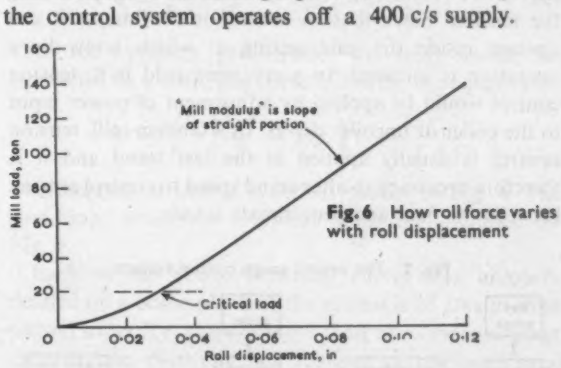
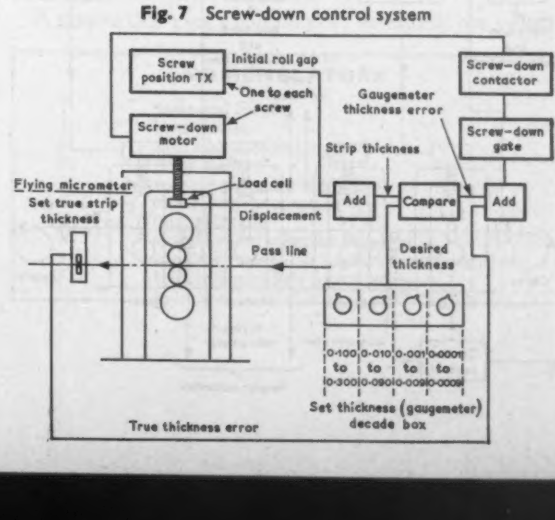


Fig. 6 How roll force varies with roll displacement

Fig. 7 Screw-down control system



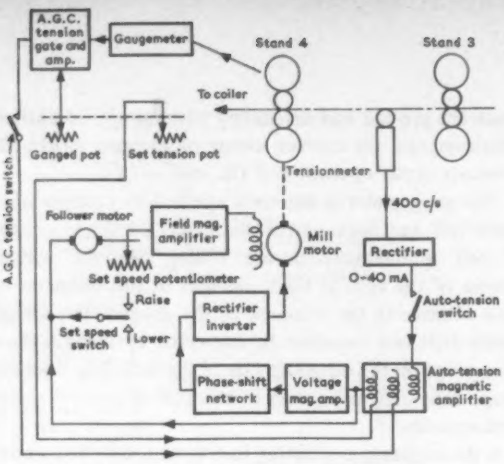


Fig. 8 Tension control circuit on the fourth stand

Thus the overall system of screw-down control includes two control loops:

- a The gaugemeter control loop which deals with fast variations in gauge.
- b The flying micrometer loop, which is slow, and which corrects the gaugemeter system to ensure long-term accuracy.

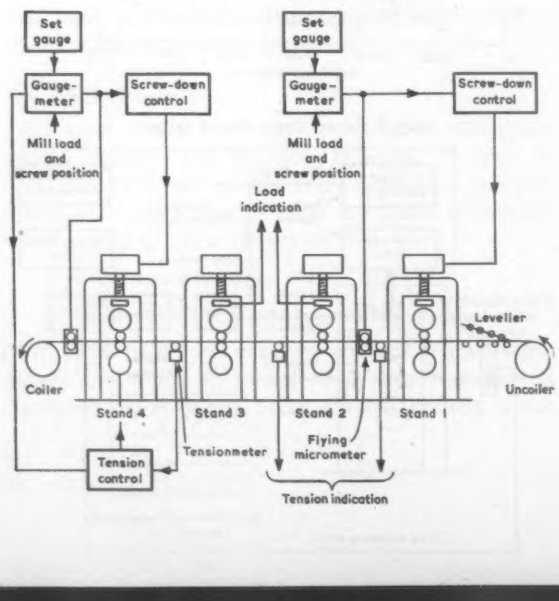
Both screw-down motors are linked together by a magnetic clutch which is energized when gauge is automatically controlled. If the operator wishes to correct the shape of the cross-section of the strip, he can operate each screw-down motor independently, a.g.c. being muted automatically when individual screw motors are energized.

Protective circuits ensure that the mill cannot be overloaded by the action of a.g.c. or cause the strip to slip in the roll gap.

Tension control of gauge

Small variations of gauge can be controlled by altering the tension. Since tension control is continuous it can operate inside the gate setting at which screw-down operation is initiated. In a reversing cold mill, tension control would be applied by adjustment of power input to the coiler or uncoiler drives. In a tandem mill, tension control is usually applied at the last stand and it is therefore necessary to alter stand speed to control tension between the final and penultimate stands.

Fig. 9 The overall gauge control system



This inter-stand tension is measured by a single roll tensionmeter, which fulfills two separate functions:

- a Automatic control of 3 and 4 inter-stand tension at a preset figure—*auto-tension.*
- b Automatic control of strip gauge by bucking or boosting the *auto-tension* control.

This latter system works in conjunction with automatic screw-down control to form a combined loop providing coarse (screw-down) and fine (tension) control.

Fig. 8 shows a simplified schematic diagram of the tension control circuits.

The control is arranged to vary the desired tension set by the operator $\pm 20\%$. If gauge is not achieved when the 20% limit is reached, the screws are operated.

Percentage control of tension is achieved by ganging a potentiometer to the 'set tension' regulator to vary the width of a diode gate in the amplifier. This amplifier accepts a signal proportional to gaugemeter error, and after amplification the output feeds a buck/boost winding on the auto-tension magnetic amplifier. Hence if the 'set tension' regulator is in its zero position the diode gate will be closed. When in the maximum position the diode gate is fully open, allowing maximum tension control to be exerted.

THE COMPLETE CONTROL SYSTEM

In the previous paragraphs systems of screw-down and tension control have been described. It is now possible to show how the various types of control can be married to form a complete system of automatic gauge control for a four-stand tandem mill.

Screw-down control only is used on the first stand, where the object is to prevent variations of gauge from being fed into the mill. Since the gate setting can be 0·0003in, 0·001in, or 0·0005in, (0·001 being the usual setting), any variations in strip thickness outside this limit are removed. Gauge control using tension is not a practical proposition at this stage since the material is relatively thick and the effect of tension would be small.

The second and third stands reduce the strip to a predetermined gauge before it enters the last stand. The reduction (or 'draft') in these stands is determined by the required final gauge and the metallurgical properties of the strip.

The output from the last stand is the product which may be sold to the customer direct, or after further processes have been carried out as described in the introductory paragraphs. The quality of the strip, the surface finish and gauge are therefore of paramount importance. To obtain the close tolerances specified, stand four is equipped with automatic gauge control using a combined system of screw-down and tension control, the basic scheme being that shown in Fig. 9.

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Acknowledgement

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Where large errors occur, a simplified switching criterion can give dead-beat response and switching level can be set by velocity feedback. Linear-operation velocity-error can be eliminated by feeding back velocity through a non-minimum-phase network

Torque- and velocity-limited servo-mechanisms

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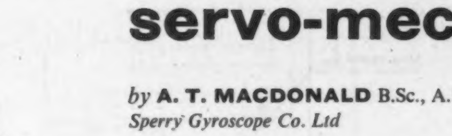
Sperry Gyroscope Co. Ltd

ALL SERVO-MECHANISMS HAVE AN UPPER TORQUE LIMIT; and also an upper velocity limit, since there is always at least some mechanical damping associated with the load. In this article we attempt to suggest various methods of control for such systems, both in the linear and non-linear regions.

Saturating servo-mechanism control

SERVO-MECHANISM WITH NO VELOCITY DAMPING Consider a second-order servo-system with no inherent damping, as shown in Fig. 1. Let the torque applied to the inertia

Fig. 1



load I be governed by the equation torque $T = |T|$ sign θ_ϵ. At any instant therefore the output motion will satisfy the equation.

$$\ddot{\theta} = T/I \tag{1}$$

Let the torque reverse from $+T$ to $-T$ with an initial velocity of $+\dot{\theta}_0$. The distance θ travelled before the velocity reaches zero is

$$\theta = \frac{\dot{\theta}_0^2 I}{2T} \tag{2}$$

Therefore for best performance the relay should be controlled by a switching curve following the equation

$$\theta_\epsilon = \frac{\dot{\theta}|\dot{\theta}|I}{2T} \tag{3}$$

A diagram of such a system is shown in Fig. 2.

In the system of Fig. 2, after a step error of $+\theta_\epsilon$ occurs, the load will accelerate in a positive direction to reduce the error. As the position error reduces, the amplitude of the non-linear velocity-feedback will increase until eventually equation 2 will be satisfied and the torque will reverse. The velocity will reach zero at the same instant as the error reaches zero. After the switching instant the non-linear velocity-feedback will follow the error down to just keep the relay over at negative torque. The switching curve and a typical response are shown on the phase plane, Fig. 3. This system is well known (*1, 2*).

SERVO-MECHANISM WITH LOAD-VELOCITY DAMPING The above example has no velocity limit. This is never so in practice, since there is always some damping associated with the load. Let damping be proportional to speed. The output motion equation is now

$$\ddot{\theta}I + \dot{\theta}K_v = T,$$

where K_v is the damping coefficient Let the torque be reversed from $+T$ to $-T$ when the initial velocity is $+\dot{\theta}_0$, then the distance travelled before the load comes to rest is

$$\theta = \frac{IT}{K_v^2}\left[\frac{K_v\dot{\theta}}{T} - \log_e\left(1 + \frac{K_v\dot{\theta}}{T}\right)\right] \tag{4}$$

Thus for optimum performance the relay should be controlled by a switching curve following the equation.

$$\theta_\epsilon = \frac{IT}{K_v^2}\left[\frac{K_v\dot{\theta}}{T} - \log_e\left(1 + \frac{K_v\dot{\theta}}{T}\right)\right]$$

The diagram of such a system is shown in Fig. 4. The switching curve with a typical trajectory is shown on Fig. 5.

Each of the above switching curves was uniquely defined on a phase plane. If the system is of greater than second order, i.e. there is more than one energy-storage element, the switching law requires multi-dimensional phase space for its presentation.

A system that uses a computer to determine the switch-

NOMENCLATURE

T	saturated torque
I	load inertia
θ	load displacement angle
θ_ϵ	error angle
K_v	velocity damping coefficient
K	multiplicative constant
τ_1, τ_2 etc.	time constants
S	singularity of complex function
p	complex variable in Laplace transformation
θ_ϵ'	velocity-limited switching angle

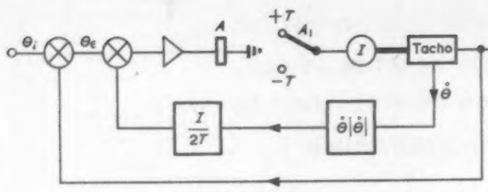


Fig. 2

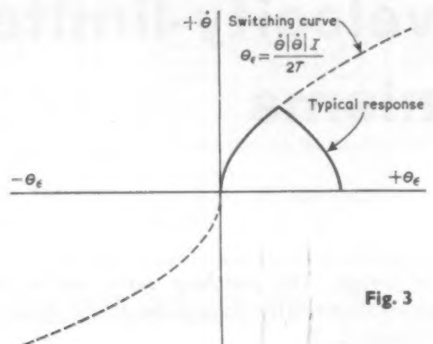


Fig. 3

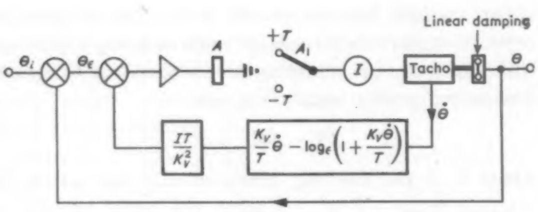


Fig. 4

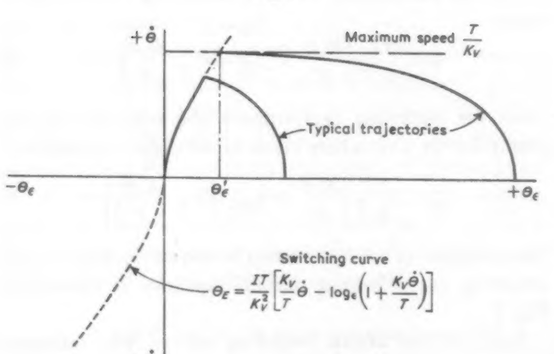


Fig. 5

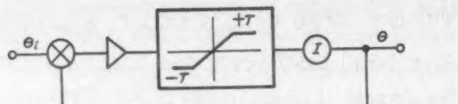


Fig. 6

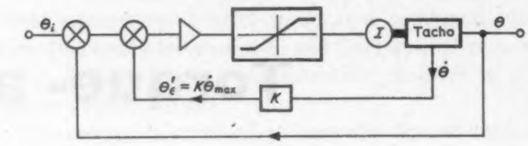


Fig. 7

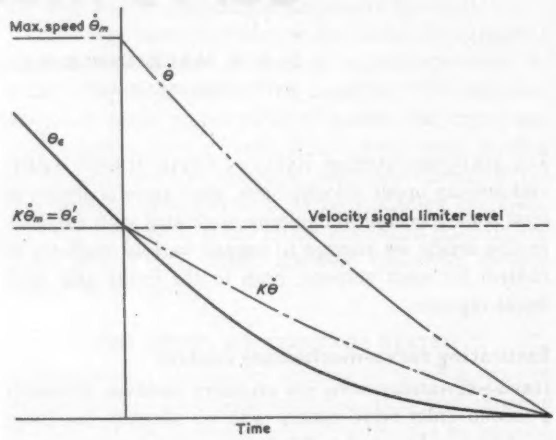


Fig. 8

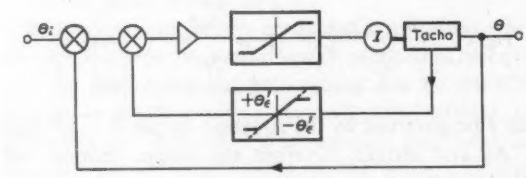


Fig. 9

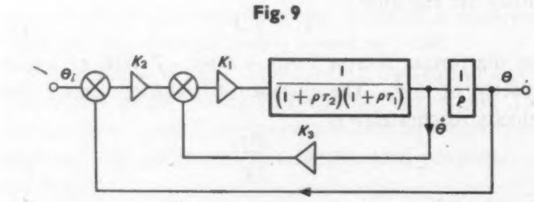


Fig. 10

ing instant, so that the energy in each energy storage element becomes zero at zero error, is described in reference *3*.

SWITCHING CRITERION FOR VELOCITY-LIMITED SYSTEM

Velocity-limited systems, e.g. a system with linear load damping as shown in Fig. 4, will now be considered more fully.

It will be seen from the phase plane diagram in Fig. 5 that for large errors the system will have nearly reached its maximum speed. The switching criterion then reduces to a single value of θ_ϵ, say θ'_ϵ. This simple criterion will apply to any order of system with any damping law. The actual value of θ'_ϵ will, of course, be determined by such system characteristics.

Linear system with saturated zone

A system which has a linear zone for small errors and a saturated zone for large errors will behave similarly to a relay servo-mechanism for large errors. Such a system is shown diagrammatically in Fig. 6. For large error signals the simple switching criterion as established above can be used. The position-error switching level θ'_ϵ can

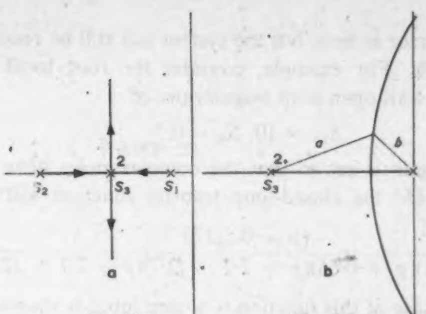


Fig. 11a Fig. 11b

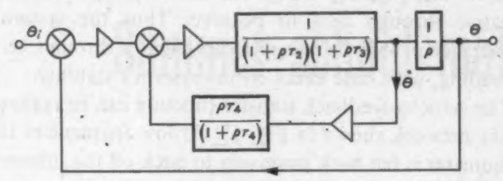


Fig. 12

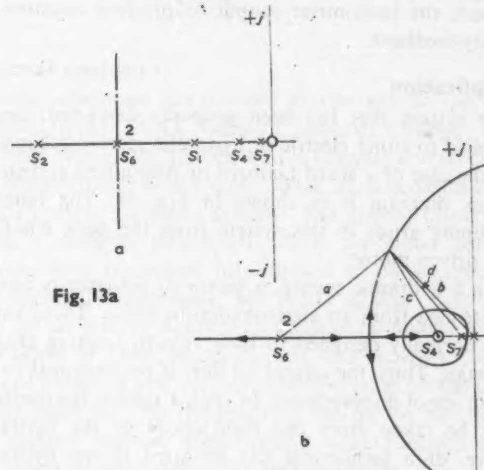


Fig. 13a

Fig. 13b

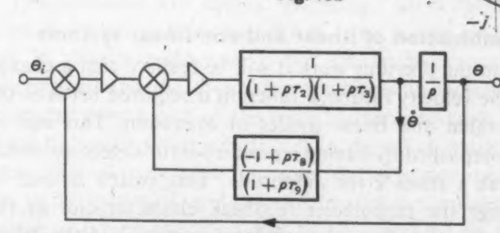


Fig. 14

conveniently be derived from a velocity feedback signal. Thus the velocity signal for maximum speed is scaled to compare with θ_ϵ'. This system is shown in Fig. 7. The switching curve is shown in Fig. 8, where θ_ϵ and $\dot{\theta}$ are shown against time measured from the switching instant. Load damping proportional to speed has been assumed. If $\theta_\epsilon > K\dot{\theta}_m$ a positive torque is applied, as θ_ϵ drops below the $K\dot{\theta}_m$ the torque is reversed. The load decelerates and, as will be seen from the figure, the error signal is always less than the velocity signal, so that the negative torque exists until both signals tend to become zero simultaneously. However, as the difference between the signals reaches a small value the system enters the linear zone, and the performance will follow linear theory. Thus for large error signals the torque will be switched at nearly the optimum point for quick recovery, whilst the performance in the linear zone will be appropriate to a linear servo-mechanism with velocity feedback.

It is convenient to keep the switching level θ_ϵ' and the slope of the velocity feedback separate. This can be done by increasing the velocity-feedback gain-factor K and putting the velocity signal through a limiter. This system is shown in Fig. 9. The switching curve for this system is also shown in Fig. 8. The torque reverses when θ_ϵ drops below the velocity-signal-limiter level, and this level can be adjusted to give the optimum switching point without affecting the linear region performance.

Reduction of steady-state velocity error

The system previously described was assumed to have inherent velocity-damping plus direct velocity feedback. Thus when a steady velocity input is being followed a velocity error will exist. This velocity error is generally undesirable and attention will now be given to methods of reducing and even eliminating it.

The velocity error can be reduced by increasing the major loop gain, but instability in both major and minor loops limits the extent to which the error can be reduced, and it can never be zero. Also, such a solution increases the band-width of the servo-mechanism, which may be undesirable if there is noise with the signal.

In the linear region the system will typically have the transfer diagram shown in Fig. 10, where τ_1 is the time constant associated with the inherent linear damping and τ_2 is the time constant due to other lags such as motor field inductance. The minor and major loop root loci are shown in Figs. 11a and 11b respectively. From 11b the velocity error coefficient is $S_3^2/(a^2 \times b)$ seconds. The velocity error due to the direct velocity feedback can be eliminated by introducing a high-pass filter in the velocity feedback. The filter can have a transfer function $p\tau/(1 + p\tau)$ and the system transfer diagram is shown in Fig. 12. The minor and major root loci for the new system are shown in Fig. 13a and 13b respectively. From Fig. 13b the velocity error coefficient is $(S_6^2 \times S_7 \times d)/(S_4 \times a^2, b, c)$ seconds. Thus since S_7 is approaching the origin, the velocity error is reduced.

For the velocity error to be zero, a double pole must exist at the origin in the major open-loop transfer function. In the minor root locus of Fig. 13a, if the zero at the origin could be placed on the real axis in the right half plane, then the pole S_7 could be positioned at the origin whilst still having a finite minor loop gain. The velocity feedback transfer function will be of the form $-(1 - p\tau_8)/(1 + p\tau_9)$. The system transfer diagram is shown in Fig. 14 and the minor and major root loci in Fig. 15. From Fig. 15b it will be seen that, since S_{11} is at the origin, the velocity error is zero. The response to a step input in the linear region must overshoot, since the

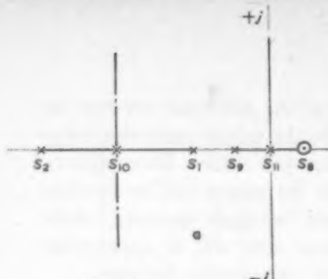


Fig. 15a

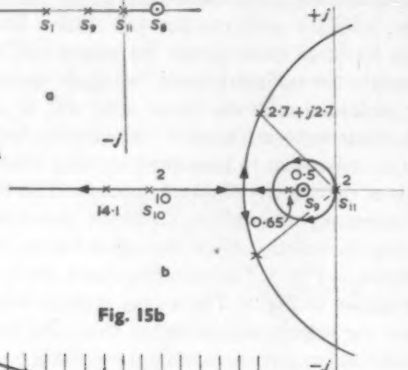


Fig. 15b

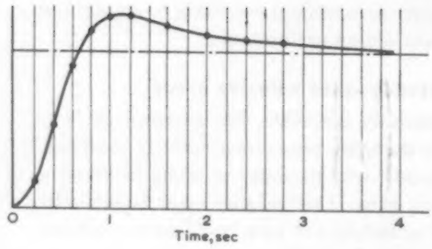
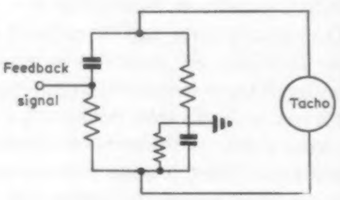


Fig. 16

Fig. 17



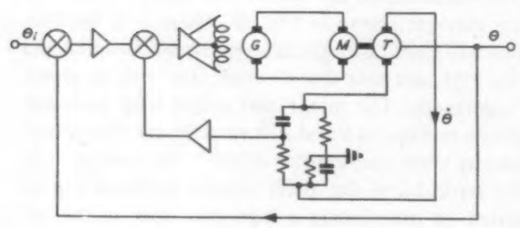


Fig. 18

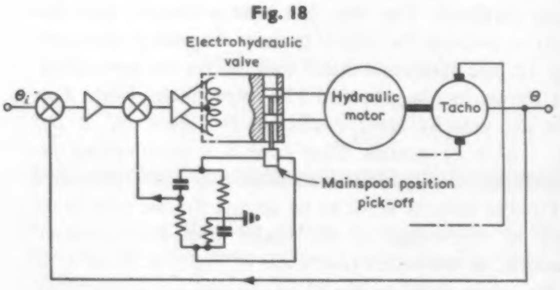


Fig. 19

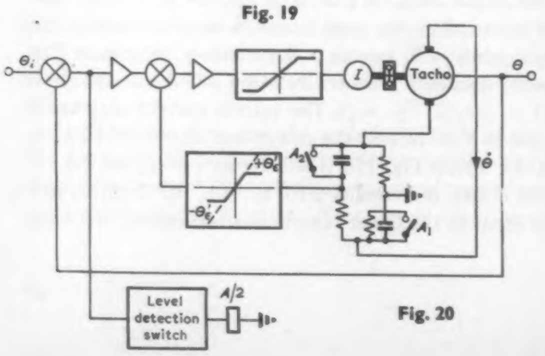


Fig. 20

velocity error is zero, but the system can still be reasonably stable. For example, consider the root locus of Fig. 15b, with open-loop singularities of

$$S_{10} = 10, S_9 = 0{\cdot}5.$$

If the gain is set so that the complex poles have an angle of 45° the closed-loop transfer function will be

$$\frac{(p + 0{\cdot}5)270}{(p + 14{\cdot}1)(p + 0{\cdot}65)(p + 2{\cdot}7 + j2{\cdot}7)(p + 2{\cdot}7 - j2{\cdot}7)}.$$

The response of this function to a step input is shown in Fig. 16. The pole S_{11} in Fig. 15a can be positioned from negative through zero to positive. Thus the system's velocity error can be varied from lagging through zero to leading, with little effect on the system's stability.

The velocity-feedback transfer-function can be realized in the network shown in Fig. 17. At low frequencies the tachometer is fed back positively to back off the inherent load damping; at the frequency of instability the network inverts the tachometer output to produce negative velocity-feedback.

Application

The system that has been generally described can be applied to either electric or hydraulic servo-mechanisms. In the case of a Ward Leonard or Amplidyne system the block diagram is as shown in Fig. 18. The inherent damping arises in this system from the back e.m.f. of the driven motor.

In a hydraulic system, a motor or actuator is usually controlled from an electrohydraulic valve. These valves are normally designed to have velocity-limiting characteristics. Thus, the output oil flow is proportional to the main spool displacement. In such a system the feedback can be taken from the main spool of the hydraulic valve, or a tachometer can be fitted to the hydraulic motor (Fig. 19).

Combination of linear and non-linear systems

From the previous work it will be realized that a change in the velocity feedback function is required between the saturated and linear modes of operation. This can be accomplished by having a position-error-detection switch set at a small error amplitude. This switch is used to change the tachometer feedback characteristics as the system moves from one mode of operation to the other. A diagram is given in Fig. 20.

If an analogue system of measurement is being used, it is common practice to have coarse and fine measuring elements. The position feedback is switched from the coarse to the fine system when the error is small. It is usually possible to use the same switching system to change the velocity feedback characteristics.

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PART 2

There is a great need for a gathering together of the many threads in the wide field of engineering mathematics. To begin with, we could swallow our insular pride and adopt American conventions

Summer-school mathematics for control engineers

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Spectral analysis

Tuesday afternoon was devoted to a lecture on spectral analysis by Mr D. G. Watts of Imperial College. His audience was vastly amused by his opening comment to the effect that he would now 'break all precedents and actually draw a control system', the system displayed being a skeleton statistician. After an initial period devoted to a theoretical introduction to power spectra and correlation functions, Mr Watts passed on to the case of an infinite number of records of finite length. The effect of finite length records was shown to be a 'sort of smearing and confounding operation on the true power spectrum'. As the length of the record increases, the spectral window approaches a delta function and the spectrum approaches the true spectrum.

The next step was defined as facing 'harsh reality'. Here, there was a finite number of finite record lengths, and in this case the true power spectrum cannot be determined, and the covariance function can merely be estimated over a part of the record length available. In order to handle the practical case, a theory of statistical estimation of covariance functions and of power spectra has to be developed, and this was treated in some detail. Where a power spectrum has to be estimated from a single length of record, there are three interdependent stages: specification of what is required, collection and reduction of data, and computation. Some practical remarks about each of these stages were made, in particular the question of choice of spectral window. The results generally obtained are at best only estimates, and it was stressed that there is no substitute for more and longer records.

Best and Optimum systems

Dr S Katz of Imperial College was the first of two speakers who were to present more than one paper. His first paper, which commenced the proceedings on the Wednesday, was entitled 'Best Linear Control in the Presence of Noise', and was devoted to considering the problem of regulating some continuous process in the presence of random disturbance. The key words were to be 'noisy' and 'linear'. After demonstrating his agility in removing the previous afternoon's chalk from the blackboard, Dr Katz began with the basic definition of a stationary random process and its Fourier decomposition. He then considered the significance of the impulse response and convolution methods, and defined an output input operator $\mathscr{K}$ and the condition that such an operator should be stable. Since a stable operator yields a stationary noise when driven by a stationary noise, its Fourier transform $k(\omega)$ can be determined by division. A table was then developed showing the parallel impulse response and frequency response operations for a number of types and combinations of operators. The important point was made that the algebra of frequency response functions exactly follows the algebra of operators.

Some time was now spent on the implications of the words 'physically realizable', which were taken to mean that a system was stable and retrospective. Singularities on the ω-plane were examined in detail, and the difficulty of distinguishing whether a particular singularity in the lower-half plane arose from instability or from a predictive nature in the system was discussed. The final few minutes were devoted to the Wiener problem. A number of questions was put to the lecturer, but most of the available question time was taken up by a demonstration by Professor Brown of an alternative approach using autocorrelation functions only. Dr Katz, however, remained unconvinced, since he could justifiably claim that the theory he had described was more general in character.

The other speaker who was to be given an official second innings was Dr A. T. Fuller of Cambridge

University. His first talk was devoted to optimum non-linear control systems with transient inputs, and he was to concern himself largely with control systems which are subject to saturation. He began by mentioning the work of L. S. Pontryagin and R. Bellman in particular. The system which was the basis of his material is shown in Fig. 2. Here the controller is assumed to be physically realizable, where this is defined as meaning retrospective only, and the system input is to be in the nature of a step function. The problem is to design the controller so as to minimize some given criterion of performance associated with the system error, such a criterion being represented generally by

$$\int_0^\infty q(E)dt,$$

where q is a weighting function appropriate to the economics of the system. The concept of phase space was again utilized, and Dr Fuller demonstrated the important result that the optimum control input to the main process is an instantaneous linear or non-linear function of the input and output phase co-ordinates.

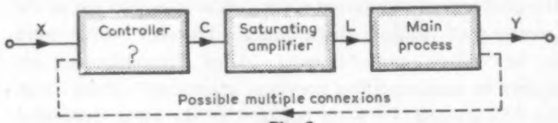


Fig. 2

Where the amplifier output takes only the maximum and minimum values allowed by saturation, the result is that the optimum controller is defined by a switching hypersurface in phase space.

Having demonstrated the nature of the optimum controller, the speaker went on to present an outline of Pontryagin's method for calculating the required function of the phase co-ordinates. Only a special simple class of problem was considered, and this without proof, but the appropriate references were adequately supplied. The lecture as a whole was directed primarily to the engineers present, and as such was a careful and easily understandable presentation of the results of mathematical processes which it would have been impossible to consider in detail in the time allocated.

On Wednesday afternoon, Dr Florentin of Imperial College discussed the Chapman-Kolmogorov and Fokker-Planck equations. Unfortunately the introduction was largely inaudible. The main material of the lecture was restricted to Markov processes, but these are of very wide application. Dynamic systems driven by white noise, for example, always yield Markov processes. The Chapman-Kolmogorov equation arises when classifying trajectories in phase space between an initial state and a final state by considering their passage through intermediate times t_i. The equation was described as a consistency relation for Markov processes. It was shown that when a continuous dynamic system is under consideration the equation can be converted into a partial differential equation which is often more convenient. After detailing the appropriate mathematics, Dr Florentin derived the resulting Fokker-Planck equation. It was clear that the concepts discussed form the basis of a much more developed theory of dynamic systems driven by random processes, and the speaker ended with a prophecy that the two equations would come to much greater prominence in the near future.

On Thursday the lecturers of the previous morning presented their second papers. This time it was Dr Fuller's turn to speak first, and he extended his theories of optimum control systems to cover the case of random inputs. The same basic system was considered and a similar performance criterion specified. After a detailed classification of random signals and consideration of the methods for their generation, the speaker demonstrated by reasoned argument that the optimum control input to the main process is an instantaneous non-linear function of the input and output phase co-ordinates, and also that in the relay case the concept of a switching hypersurface developed for transient inputs applies equally well when the input is random. The results were stated to be applicable when the random input is a Markov process, a Gaussian process, or a Gaussian signal plus Gaussian noise. During the question time which followed, Dr Fuller dealt satisfactorily with the problem of backlash, but further questioners drew attention to the fact that the methods discussed produced the absolute optimum regardless of expense and required a complete specification of all the phase co-ordinates of the main process.

Dr Katz entitled his second paper 'Best End Point Control Actions in the Presence of Noise'. He began with further considerations concerning the operator $\mathcal{K}$ and the relations between feedback and feedforward control in noiseless and noisy systems. He described feedback as representing a policy question and feedforward as representing a schedule question. These represent two problems in the calculus of variations. The first considers the input to be applied at all times up to some deadline as a function of the current state of the output and the time remaining. The second considers the output as inaccessible to measurement except at an initial time, breaks the control loop and seeks the best schedule of input to follow from the initial time up to the known deadline. The best schedule was claimed to be obtained by the method of Pontryagin, and the best policy by the methods of dynamic programming; both these were treated in considerable detail. Dr Katz admitted that as yet he had found only one problem which he had solved by the two methods, and he had not come to any conclusion about the relative advantage of either one over the other.

A neglected field

The afternoon speaker on the Thursday, Professor E. M. Wright of Aberdeen University was introduced as the only real authority in this country on his subject of

difference-differential equations. He said that he had for some time realized the importance of this neglected field of study for control engineering applications, but that repeated attempts to interest the appropriate governmental committee had brought forth no more than promises of further communications which were never forthcoming. The subject dealt with a generalized study which would include the whole theory of differential equations and that of difference equations as simple special cases. The majority of the literature at present available dealt only with particular equations arising in specific situations. It was Lord Cherwell who had first interested the professor in this subject in connexion with a proof of the prime number theorem.

A linear equation described as frequently occurring was

$$y'(x + 1) = -ay(x).$$

Trying $y(x) = e^{sx}$ as a solution leads to the well-known transcendental equation

$$se^{s} = -a,$$

which has an infinity of roots yielding a general solution

$$y(x) = \sum_r (A_r e^{s_r x} + \bar{A}_r e^{\bar{s}_r x}),$$

where the A_r are determined by the boundary conditions. The solution tends to zero for $a < \pi/2$. The Russians were stated to have done considerable work on the solution of homogeneous linear equations with constant coefficients of the type

$$\sum_{\mu=0}^{m} \sum_{\nu=0}^{n} a_{\mu\nu} y^{(\nu)} (x - \mu) = 0.$$

Pontryagin's work and the plateau method were mentioned in particular. The corresponding equation to the trivial algebraic case $ax + b = 0$ was shown to be

$$(pz + q)\, e^{z} + uz + v = 0,$$

which reduces by simple transformations to one or other of

$$ze^{z} + a, \text{ or } e^{z + a} = (z - b)/(z + b),$$

accordingly as $pu = 0$ or $pu \neq 0$. The speaker said that he had done considerable work on these equations and that this had been subsequently extended by a pupil of his at the cost of still further complexity. In the more general field, success was stated to be limited and it was clear that a vast amount of work needs to be done before anything like a coherent general theory is produced.

Interacting systems

The last morning began with a talk by Dr D. S. Mitchell of Rolls-Royce Ltd on the stability of interacting control systems. He was concerned with the control of processes with more than one input and more than one output where each of the input variables affects all of the output variables. Typical examples quoted were distillation columns, aircraft propeller and turbo-jet engines, steam generating plants, and nuclear reactors. The general equations representing such systems were derived, summation notation being used throughout. The practical interpretation of the results presented was that feedforward paths have to be provided as well as feedback paths, it being impossible to achieve absolute invariance by relying upon feedback control alone. The notation selected for representing the desired equations was somewhat clumsy and tended to confuse the issues involved. It was pointed out to the speaker, somewhat unkindly, that his lengthy mathematics could have been presented in much shorter and more easily understandable form had matrix notation been adopted throughout.

Method without mathematics

The penultimate paper was the only one to be presented jointly by two speakers. It consisted of a description of the Simplex method of finding optimum conditions for a chemical process developed by Dr F. R. Himsworth and Mr W. Spendley of I.C.I. Dr Himsworth, amidst considerable applause, began by saying that not only had he come before his audience without any mathematics, but also he was not even proposing to present anything which was soluble in principle. He explained the method in terms of two variables where the objective was simply to maximize some response function of the two variables. This involved the measurement of the response function at three points in the plane of the variables forming the vertices of an equilateral triangle. The next point is selected so that it forms a second equilateral triangle together with two of the original points and gives an overall improved result. The procedure is repeated so long as improvement is possible until the optimum is reached, with various special rules being introduced to avoid wander owing to random error and endless circling around false maxima. The system was shown to be adaptable to systems involving k variables. Mr Spendley then expounded something of the mathematics behind the method, and both speakers replied in some detail to questions about the special problems caused by ridges.

Integral equations

So, finally, the last item of the week had arrived. Mr J. A. P. Hall, head of the Mathematics Department at Hatfield, who had introduced so many of the speakers during the week, now occupied the platform himself. The task which he had chosen was the difficult one of covering the immense field of integral equations in the space of one hour. After commenting upon the unsuitability of Friday afternoons for mathematical topics, Mr Hall stated that he proposed to take his audience on a general conducted tour of the subject rather than treat any particular aspects in detail. He claimed that this was necessary because control engineers, if indeed they knew anything at all about integral equations, were likely to be familiar only with the Wiener–Hopf type, and would thus have an extremely distorted view of the subject as a whole.

The tour began with the case of an elastic string of

assumed unit length under a continuously distributed load of linear density $W(x) > 0$. When the problem is to define the load which produces a given deformation, the equation arising is the linear Fredholm equation of the first kind. If the distributed load is taken to have a time-varying linear density, $W(x) \sin \omega t$, and a periodic oscillation of the string is assumed, then a non-homogeneous linear Fredholm equation of the second kind can be derived. Both of these cases were reviewed in brief. Mr Hall then demonstrated that a rotating shaft produced the homogeneous case, but that releasing one end of the shaft gave rise to an integro-differential equation which in certain cases reduced to a linear non-homogeneous Volterra equation of the second kind. Volterra equations arise whenever there is a preferred direction for the independent variable. Abel's problem was then investigated and a linear Volterra equation of the first kind derived. An immediately discernible difference between Fredholm and Volterra equations is to be found in the integral limits, which are constant in the former case and usually $0 - x$ in the latter, but it is possible to include the Volterra equation under the general heading of the second kind of Fredholm equation.

The connexion between the theory of linear integral equations and the theory of simultaneous linear algebraic equations was mentioned, and some time was spent in extending the theory to the whole class of L_2 kernels. Clearly, Mr Hall could easily have filled several hours with the material which he had to hand, but time permitted only a very sketchy outline of some further special types of kernel.

The whole proceedings were then brought to a close by the Principal of the College, who followed what he described as 'Mr Hall's whirlwind performance' with a few words designed to restore the company to calmer waters and send them away with the realization that what they had been considering during the week was a genuine representation of the mathematics of industry as it is today.

The ever-increasing necessity

There is no doubt whatever that the week was a great success, and all credit must go to Mr Hall and his staff who had made such thorough and careful preparations for every aspect of the summer school. The arrangements included a visit to Hatfield House and a display of books relating to the topics of the course. All those who attended must have gone away thoroughly convinced of the ever-increasing necessity for engineers to have an understanding of advanced mathematical techniques. It is also equally important that mathematicians should have a sufficient appreciation of the needs of the modern research engineer, and for this reason it was to be regretted that more pure mathematicians did not avail themselves of the opportunity presented by this particular week.

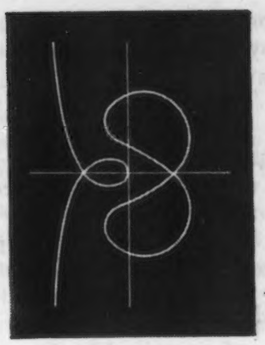
There is a great need today for a gathering together of the many threads which are being developed in their separate ways in the wide field of engineering mathematics. An obvious first step is to have some sort of discipline in the use of symbols and in the methods of formulating problems. It was all too plain to see that each mathematical and engineering 'tradition' was still clinging to the symbols of its early research, and, in view of the great preponderence of American textbooks now on the British market, would it be too much to ask that we swallow our insular pride and adopt their conventions? The use of a star notation to denote a Laplace transform, for example, seems quite indefensible. There were many other similar examples during the week.

It would be appropriate here to draw final attention to the gist of the remarks with which Mr Parks concluded his talk on Monday afternoon. The mathematical training of engineers at many of our universities has stood still for too long and to a greater or lesser degree is failing to provide the background needed for the present generation dedicated to research. This problem is, of course, fully appreciated in many circles, but there must clearly be some doubt as to whether the means being taken to alleviate it are likely to produce concrete results with sufficient speed. There must be a much closer integration of mathematics and engineering at all levels of education, and syllabuses of examining boards which are out of touch with modern developments must be drastically and immediately revised; failure to effect much needed reforms will seriously impede progress in the western world. *End*

These were the papers

Introductory survey, *by* J. F. Coales (*Department of Engineering, University of Cambridge*)
Time series and *z*-transform methods, *by* A. J. O. Cruikshank (*Queen's College, Dundee, University of St Andrews*)
Non-linear differential equations: Liapunov's methods, *by* M. J. Cartwright (*Girton College, University of Cambridge*)
Application of Liapunov's stability criteria, *by* P. C. Parks (*Department of Aeronautics and Astronautics, University of Southampton*)
Variational methods, *by* M. J. McCann (*Department of Electrical Engineering, Imperial College*)
Operational methods for sampling systems, *by* B. M. Brown (*Royal Naval College, Greenwich*)
Spectral analysis, *by* D. G. Watts (*Department of Electrical Engineering, Imperial College*)
Best linear control in the presence of noise, *by* S. Katz (*Department of Chemical Engineering, Imperial College*)
Optimum non-linear control systems with transient inputs, *by* A. T. Fuller (*Department of Engineering, University of Cambridge*)
Chapman–Kolmogorov and Fokker–Planck equations, *by* J. J. Florentin (*Department of Electrical Engineering, Imperial College*)
Non-linear control systems, *by* A. T. Fuller (*Department of Engineering, University of Cambridge*)
Best end-point control action in the presence of noise, *by* S. Katz (*Department of Chemical Engineering, Imperial College*)
Difference-differential equations, *by* E. M. Wright (*King's College, University of Aberdeen*)
Stability of interacting control systems, *by* D. S. Mitchell (*Rolls-Royce Ltd*)
The simplex method, *by* F. R. Himsworth *and* W. Spendley (*I.C.I. Ltd*)
Integral equations, *by* J. A. P. Hall (*Department of Mathematics, Hatfield College of Technology*)

NUMBER EIGHT OF THE SERIES PART B



This last instalment of a brilliant series leads to the conclusion that, while the root locus method is not a cure for every linear analytic ill, it often helps

Pole-zero approach to system analysis

by **P. F. BLACKMAN**

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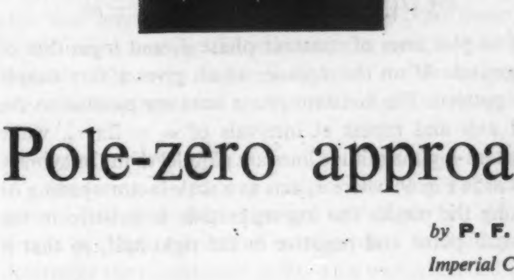
Coupled systems

In some situations, such as multi-dimensional control, two or more systems may be operating with the possibility of cross coupling between them. This implies that the output of one system may give an (unintentional) input for the other system(s), and may arise when input and output resolution axes are skewed. Fig. 7a shows two identical systems where a cross-coupling effect is assumed symmetrical and represented by the block K_c. The matter of interest is to investigate the effect of cross coupling on



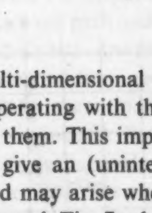


Fig. 7 a Identical cross-coupled systems
b Effect of cross coupling on closed-loop poles
c Closed-loop pole loci with constant coupling and varying gain

the closed-loop poles of a single isolated channel, and this may be examined easily by the root-locus method.

For the upper channel the two cross-coupling terms together with the lower channel form an additional parallel feedback path with the transfer

$$K_c^2 KG(p)/[1 + KG(p)]$$

so that the upper channel transfer is given by

$$\frac{O_1}{I_1}(p) = \frac{KG(p)}{1 + KG(p)\,\{1 - K_c^2 KG(p)/[1 + KG(p)]\}}$$

the negative sign in the denominator arising since it has been assumed initially that both cross-coupling terms are positive. The transfer expression may be written as

$$\frac{O_1}{I_1}(p) = \frac{KG(p)\,[1 + KG(p)]}{\{[1 - K_c^2]\,[KG(p)]^2 + 2KG(p) + 1\}}$$

where the denominator is a quadratic in $KG(p)$, and the closed-loop poles will occur for values of p such that

$$KG(p) = (-1 \pm \sqrt{K_c})/(1 - K_c^2).$$

If $K_c = 0$, the relation reduces to the normal $KG(p) = -1$. If it is assumed that K_c is small, and also that K_c^2 may be positive or negative owing to a possible difference of cross-coupling sign, the exact closed-loop pole condition yields the approximate results

K_c^2 positive: $\quad KG(p) \simeq -1 \pm K_c$
$\quad$ or $|KG(p)| \simeq 1 \pm K_c$; $\angle G(p) = 180°$

K_c^2 negative: $\quad KG(p) \simeq -1 \pm jK_c$
$\quad$ or $|KG(p)| = 1$; $\angle G(p) = 180° \pm \tan^{-1} K_c$

If K_c^2 is positive, as K_c is increased the closed-loop poles of $O_1/I_1(p)$, initially located at p_k in Fig. 7b, change into two poles moving on the 180° lines with the magnitude condition $|KG(p)| \simeq 1 \pm K_c$. If K_c^2 is negative the poles move along the constant-magnitude line $|KG(p)| = 1$, to different constant-phase lines. Also, zeros appear at the uncoupled pole locations p_k, because these poles from one channel are added into the feedback path for the other channel. The general effects are illustrated in Fig. 7b.

For situations in which K_c^2 is constant and negative, and K (the system gain) is varied, the locus of closed-loop solutions is along the constant-phase line

$$\angle G(p) = 180° \pm \tan^{-1} K_c$$

and if $KG(p)$ contains an integration and time constant the general form of these constant-phase lines will be as in Fig. 7c, where a pair crosses the imaginary axis so that the coupled systems will have reduced stability or even oscillate.

Distributed parameters

All analysis so far has been concerned with *lumped* systems for which the transfers can be represented exactly by a pole-zero pattern. It is also possible to investigate systems containing distributed parameters, such as transmission line effects which in control engineering give rise to a *pure delay* or *distance-velocity* lag. The essential characteristic of a pure delay from the frequency response point of view is that the magnitude of the transfer is unity, but the phase angle of the transfer is proportional to frequency and delay τ_d, giving the transfer

$$T(j\omega) = e^{-j\omega\tau_d}$$

where τ_d is the time for the signal to propagate down the line. For a given value of τ_d the frequency response characteristics are as in Fig. 8a, and a pole-zero pattern giving an approach to these characteristics represents an approximation to a pure delay. The simplest pattern would have a pole and zero on the real axis with the transfer

$$T_1(p) = -(p - a)/(p + a),$$

giving the phase characteristic of Fig. 8b, which provides adequate representation over a small range of ω. This transfer in series with a system of the form of Fig. 4a

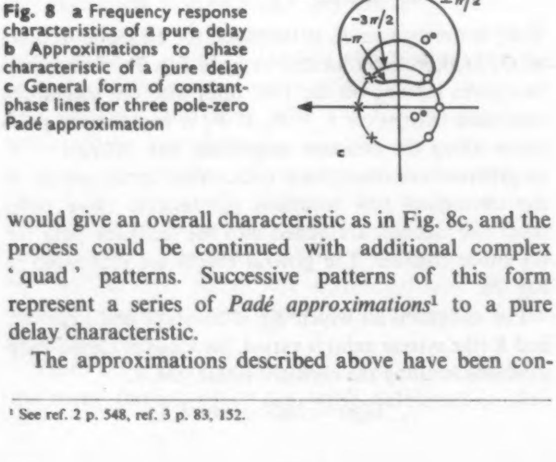


Fig. 8 a Frequency response characteristics of a pure delay b Approximations to phase characteristic of a pure delay c General form of constant-phase lines for three pole-zero Padé approximation

would give an overall characteristic as in Fig. 8c, and the process could be continued with additional complex 'quad' patterns. Successive patterns of this form represent a series of *Padé approximations*[1] to a pure delay characteristic.

The approximations described above have been concerned with representing the normal frequency response of a pure delay. For complex frequency analysis the transfer is given by

$$T(p) = e^{-p\tau_d} = e^{-(a+j\omega)\tau_d}$$

in which the phase is still given by $\exp(-j\omega\tau_d)$, but an amplitude term $\exp(-a\tau_d)$ is also required. In order to consider this transfer by the root-locus method it is convenient to adopt the logarithmic representation previously mentioned[2], and to consider

$$\log [T(p)] = -a\tau_d - j\omega\tau_d = M + j\phi$$

and to plot lines of constant phase ϕ, and logarithm of magnitude M on the p-plane, which gives a very simple line pattern. The constant-phase lines are parallel to the real axis and repeat at intervals of $\omega = 2\pi/\tau_d$, while constant-log-magnitude lines are parallel to the imaginary axis as in Fig. 9, where τ_d acts as a scale factor opening or closing the mesh. The log magnitude is positive in the left-half plane and negative in the right-half, so that if

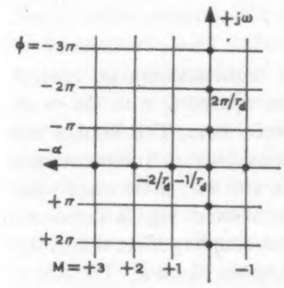


Fig. 9 Constant-phase and log-magnitude (M) lines in p-plane for a pure delay transfer (not to scale)

the log magnitude is plotted vertically the result is an inclined surface with slope proportional to τ_d, with zero along the imaginary axis. The log magnitude and phase of the pattern of Fig. 8c approximate to the correct form for a narrow strip either side of the imaginary axis within the bounds of the pattern, but outside this region the approximation fails completely.

If a system is considered with a forward path consisting of a pure delay and a time constant with associated gain K_1 as in Fig. 10a, the forward path has the transfer

$$T(p) = K_1 e^{-p\tau_d}/(1 + p\tau_1),$$

and if logarithmic representation is used the transfer becomes

$$\log [T(p)] = \log K_1 - \log |1 + p\tau_1| - \\ - a\tau_d - j[\omega\tau_d + \angle(1 + p\tau_1)]$$

which requires the *summation* of two separate surfaces, one associated with the pure delay, and the other for the time constant which is of the general form of Fig. 17 in Part 2 (Dec. 1960), except that the surface goes below the p-plane when the magnitude falls below unity. The two surfaces may be added to give the general form of Fig. 9b, with a saddle point on the negative real axis, and Fig. 9c shows the shape of the constant phase and log magnitude

[1] See ref. 2 p. 548, ref. 3 p. 83, 152.

[2] See *Logarithmic representation*, Part 3 (January 1961).

lines on the p-plane. The significant feature of this type of pattern is that there is an *infinite* number of 180° lines. Closed-loop poles are still given by the condition $T(p) = -1$ or

$$\log |\exp(-p\tau_d)/(1 + p\tau_1)| = -\log K_1$$
$$\angle(1 + p\tau_1) + \omega\tau_d = \pm n\pi, \quad n = 1, 3, 5 \ldots,$$

which gives an infinity of closed-loop poles. For an initial value of K_1 the closed-loop poles might be on a constant-M line in the left-half plane (see Fig. 9c). As K_1 is increased, the poles advance towards the imaginary axis, and eventually the pole on the 180° line from the saddle point crosses the axis and the system becomes unstable. This type of representation and investigation may also be extended to systems with distributed lags[1]

Working backwards

In considering closed-loop systems we have taken the general analysis problem through two stages. Initially the simple problem considered was: given a forward path, determine the closed-loop poles. This was succeeded by a second type of problem: given a forward path and desired positions for some closed-loop poles (normally a dominant pair), what is the compensation needed to meet this requirement? In addition there might be a need (say) to increase the velocity constant. Both these situations might be classed as working *forwards* towards an end result, some of which is specified. The third class of situation is where analysis starts from a closed-loop transfer specified to a greater or lesser extent, and the problem is to work *backwards* to obtain the corresponding open-loop transfer. This is then probably followed by the problem of compensating a given forward path to obtain the required forward path transfer. The general problem of working backwards is the extensive field of *system synthesis*[2], and in this section only a few introductory ideas are presented.

Suppose that the closed-loop transfer for a unity feedback system is specified as

$$\theta_0/\theta_1(p) = K_v Y(p),$$

the pole pattern for $Y(p)$ being as in Fig. 11a, and it is required to find the corresponding open-loop transfer $KG(p)$. The normal closed-loop relation $K_v Y(p) = KG(p)/[1 + KG(p)]$ may be written to yield $KG(p) = K_v Y(p)/[1 - K_v Y(p)]$. Hence *open-loop* poles occur for values of p such that $K_v Y(p) = +1$, corresponding to points along the 0° line of the closed-loop pattern. In fact the combined 0°, 180° lines for both open- and closed-loop patterns are the same. This may be shown by splitting each side of the closed-loop expressions into real and imaginary components when it will be found that Im $Y(p) \propto$ Im $G(p)$. Thus both imaginary components vanish along the same loci in the p-plane, and the vanishing condition also gives the combined 0° 180° lines for open- and closed-loop expressions. The normal situation is that the closed-loop transfer $K^v Y(p)$ must be

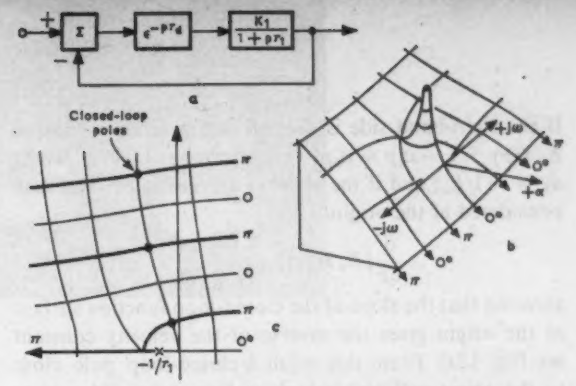


Fig. 10 a System with time constant and pure delay
b General form of surface representing system of a in the vicinity of the origin in the p-plane. Log magnitude is plotted vertically
c Constant-phase and log-magnitude lines for b

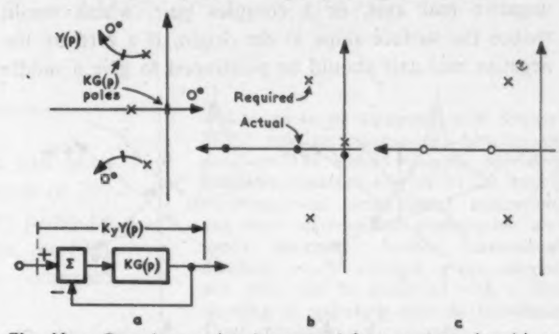


Fig. 11 a Open-loop poles determined from a given closed-loop pattern
b Required poles of $KG(p)$ in a, and actual poles
c Compensation pattern for b

unity at the origin to give perfect static alignment, which implies a pole at the origin from the result above, and also that $K^v = 1/Y(0)$, so that other open-loop poles will be located on the 0° lines of $Y(p)$ at points such that $Y(p) = Y(0)$. Thus for Fig. 11a the required open-loop poles might be located as shown.

The open-loop poles obtained from the closed-loop pattern will not normally correspond with those actually existing in the given forward path, and in principle the problem of compensation now becomes that of introducing a pattern which effectively moves the poles of the uncompensated forward path to the positions obtained working backwards from the closed-loop transfer. This requires a compensation pattern with zeros in the immediate vicinity of the unsuitable poles in the forward path, to give substantial cancellation, and poles at the required new positions. This is illustrated in Fig. 11b, c, for a forward path with an integration and two time-constants. Alternatively in this case the compensation might be tackled by introducing tacho-generator feedback with perhaps an additional network to obtain inner-loop poles at the required complex positions[3].

In addition to direct determination of the open-loop poles, information about the velocity constant can also be obtained from the closed-loop pattern. If the open-loop transfer is of the form $KG(p) = H(p)K_v/p$, where $H(p)$ contains all other poles and zeros, the closed-loop expression becomes

$$K_v Y(p) = K_v H(p)/[p + K_v H(p)].$$

[1] See ref. 4, chap. 10.

[2] See ref. 2, chap 5: ref. 5, chap. 13.

[3] See Fig. 8a, Part 7 (July 1961).

If the right-hand side is divided out, a series expansion $K_v Y(p) = 1 + a_1 p + a_2 p^2 + \ldots$ can be obtained, where $a_1 = -1/K_v$; and if the series is differentiated, and then considered at the origin,

$$\frac{\mathrm{d}}{\mathrm{d}p}[K_v Y(p)]_{p=0} = -\frac{1}{K_v}$$

showing that the slope of the closed-loop function surface at the origin gives the inverse of the velocity constant see Fig. 12a). From this result a closed-loop pole close to the origin will give a high surface slope and a poor velocity constant. For given closed-loop pole locations the velocity constant could be improved by a zero on the negative real axis, or a complex pair, which would reduce the surface slope at the origin. If a zero on the negative real axis should be positioned to give a saddle

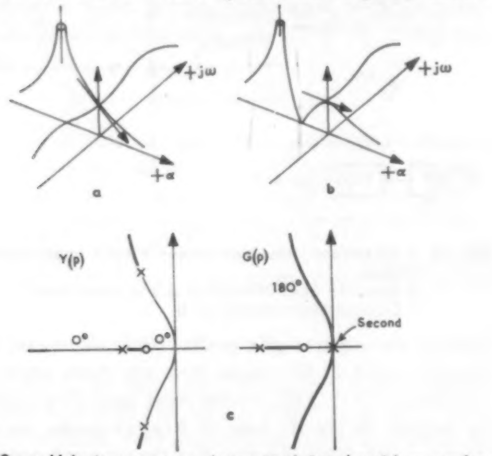


Fig. 12 **a** Velocity constant determined by closed-loop surface slope at origin
b Introduction of a zero to obtain a saddle point at the origin on the closed-loop surface to give an infinite velocity constant
c Closed- and open-loop patterns for **b**

point at the origin (see Fig. 12b), the velocity constant would be infinite, giving an *acceleration lag* system with no steady-state error for a ramp input. The position of the zero p_a, can be determined by the condition $1/p_1 + 1/p_2 + \ldots = 1/p_a$ where $p_1, p_2, \ldots$ are the pole locations[1]. If the closed-loop pattern exhibits a saddle-point at the origin, the open-loop pattern must have a second-order pole at the origin (in order that the 0°, 180° lines for both patterns may be the same) which is the significant open-loop characteristic of an acceleration lag system.

To conclude . . .

In this series the attempt has been to start by introducing the concept of complex frequency analysis as arising naturally from the solution of differential equations for linear systems, and to show that this analysis, with its emphasis on pole-zero patterns, is of direct application quite apart from subsequent development into the root-locus method for closed-loop systems. Although detailed examples have been given, the intention has also been to emphasize certain wider ideas which arise from pole-zero concepts. These are the manner in which qualitative information may often be obtained easily without any detailed calculation, and then refined into actual numerical results if this is justified from the initial information obtained. Also that systems may be analysed in alternate ways in order to obtain information about the effect of different parameter variations, which is often a very useful feature. The root-locus method also confers the ability to handle the more complicated feedback systems, such as those with more than one loop, non-unity feedback paths, or coupled systems, without the complications that may arise with normal frequency response methods: For instance, the necessity for the transition from Nyquist to inverse Nyquist plots for tacho-generator feedback, and the increased complexity of Bode diagrams for multi-loop systems.

The most valuable features of the root-locus method are its application in considering a situation qualitatively, and its use as a method of analysis for generating ideas on how to achieve some particular result, or what might be done in the face of a particular problem. Examples of this are the use of complex zeros, developments from this into invariant-response systems, or the production of delay patterns. All these ideas are relatively easily created and investigated by the root-locus method. In these more general aspects the root-locus approach perhaps has the advantage over frequency response methods because these are by their very nature restricted to considering matters in the immediate vicinity of the imaginary axis, while in complex frequency analysis one is free to roam over the entire plane, which does enable one to obtain a rather wider grasp of a situation, and to envisage additional possibilities. Of course it is only fair to state that this increased freedom, and the possibility arising from it of producing more sophisticated designs, has to be matched, particularly in control engineering, against the hard facts of practical life. For instance an adequate amount of tacho-generator ripple can neatly ruin the performance of the most elegant design.

One marked omission from the present series concerns the question of transients and the transient response of systems, which has been mentioned only in a few general terms. There is a close connexion between the Laplace transformation technique for transient calculations and many of the ideas arising from complex frequency analysis and the root-locus method. It is hoped to present subsequently some further articles, in line with the present series, but concerned with transients generally.

Finally it is not claimed that the cure for every linear analytic ill may be achieved instantly by the application of '*that there p-ology*', as a frequency response devotee put it, but it often helps.

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[1] See *Saddle points*, Part 5 (May 1961).

FARNBOROUGH PREVIEW

THE DEMAND FOR SPACE AT FARNBOROUGH THIS YEAR HAS BEEN greater than ever before: there will be the record number of 397 stands altogether—fifteen more than last year. This may partly be a reflexion of the growing exports of British aero-engines, the 1961 figures to-date representing an annual figure of £89m compared with last year's record £73·7m.

Last year saw a growing tendency amongst aircraft concerns to enter the field of industrial electronics and process control: the electronics industry understandably viewed this with mixed feelings, if only because of the enormous visible and invisible governmental support enjoyed by the aero-men. Comments since then seem to suggest that such worries were groundless, as the necessary 'transfer of skills' has turned out to be a slow process.

Reliability remains one of the great problems in aircraft control, and Texas Instruments' Normand Provost makes some interesting points on control and reliability on page 87. The DH.121 should be in the air later this year, and the VC.10 early next year. Their automatic landing systems, by Smiths and Elliott respectively, will therefore soon be competing in flight, and should provide interesting evidence on their respective reliabilities.

At the last Farnborough show, the major development in aircraft engineering was perhaps the emergence of vertical take-off aircraft. Although these are not yet commonplace, there are already two v.t.o.l. aircraft flying: Shorts' SC.1 and the Hawker P.1127. The Bristol Siddeley Pegasus lift-thrust engine, which powers the latter aircraft, has been selected for projects ranging from supersonic fighters to four-engine transports.

Flight control and navigation

Autopilots and automatic landing systems are, as always, of particular interest to control engineers. Elliott (253-4) will be showing an **air-data sensor** and a **comparison air-data sensor** designed for the VC.10. These units together feed and verify information on height, indicated air-speed and Mach number to the flight control system. **Automatic landing units** on display, also from the VC.10, will include the computer and comparison monitor assemblies, and the auto-changeover unit which brings a second monitored autopilot into action immediately any failure should occur in the first. Also to be shown is the Elliott/Bendix **Doppler radar navigational system** and its associated computer system.

The main exhibit on the Smiths stands (1-4) will be a **flight control system** for a modern transport aircraft, and will feature items now being made for aircraft such as the de Havilland DH.121 Trident and the Short Belfast, both of which are to be equipped with Smiths' SEP.5 multiplex autopilot. Also to be seen are the Kelvin Hughes **precision altimeter**, specified for the VC.10, which combines dial and digital indication, and their split-pointer presentation **air-speed indicator**. Smiths' **para-visual director**, which aroused great interest last year, will be exhibited with a film showing it operating in a de Havilland Dove demonstration aircraft.

Sperry (100) are showing a model of the flight deck of the de Havilland Trident, which carries many of their instruments including the CL.11 Rotorace **directional gyro**, the VGL.2 **vertical gyro** and associated **roller-blind flight director horizons, rate gyro units, air speed indicators, machmeters** and **vertical-speed indicators**. For the first time at Farnborough there will be a **twin gyro platform**, now in production for Nato forces, and the SP3 **light-weight autopilot**. Subject to security clearance, a **three-axes accelerometer** for missile applications will be on show.

Pye (187) are to show a **remote control and monitoring console** for use with their instrument landing system. It provides the means for starting, stopping and monitoring all the transmitters in the system.

Marconi's W.T. (19-23) and their associated companies have a wide variety of equipment. From their Canadian company is the CMA-623 **Doppler sensor**, which features a 'terrain' switch which selects the best mode for operating over 'land', 'sea', and 'smooth sea'. The CMA-601, the associated **navigation computer**, will also be on display. The M.W.T. company are to show their AD 2300B **Doppler navigator**, sales of which have now topped the £4m mark, and their 'Sixty Series' of **airborne radio and navigation aids**; the latter have been specified for the VC.10.

Murphy (174) will be showing **leader-cable equipment**, which in conjunction with a suitable altimeter and autopilot can be used for blind landing.

A transistorized **Doppler drift unit** by Ekco (193-4) is on show for the first time. This may be installed optionally with their E.190 **weather radar** as an aid to

Left: The Arma Brown gyroscopic compass

Above: Smiths' Series 4 miniature rate gyro

A multiplicity of **valves** will be found on the Saunders stand (296). Of particular interest are a **motorized spherical plug-valve**, and a **multi-way spherical plug-valve** made to withstand high-pressure surges during refuelling.

Components from the Waymouth type-4 **fuel-contents gauging system,** as specified for the VC.10, Trident, and Belfast, will be on view on the Smiths stands (1-4) for the first time. K.L.G. equipment on show will include **thermocouples, ignition harnesses,** and **igniters**. Thermocouples will include units for engine cooling-air failure warning units in production for such engines as the Rolls-Royce Dart, Tyne and Conway.

An interesting exhibit by Plessey (76-8, 91-3) will be a **pneumatic actuation and control system** for v.t.o.l. and s.t.o.l. aircraft which employ the rotating nozzle principle.

navigation. Also on the Ekco stand will be a **transistor inverter**, one of whose applications is powering the Sperry HL9 gyroscope.

On the Solartron stand (192) will be a commercially available **transistorized radar simulator**, designed for the training of radar operators.

S. G. Brown (85) will demonstrate the Gyrotwin, latest version of the **Master dynamic reference system** for aircraft. Amongst other equipment to be seen on their stand is the Arma Brown **gyroscopic compass**.

The Ministry of Aviation (stand A) will show descriptions of plans for the **application of computer techniques to air traffic control** and new **navigational aids**. The 'Head-up' display, by R.A.E., shows an entirely new **system of blind or instrument flying**. In this an optical device is used to give steering instructions to the pilot without diverting his attention from the outside world.

Ferranti (184) have a new **inertial platform** for aircraft navigation systems. This carries three accelerometers, and is stabilized by three flotation-type gyros. Also on show will be the FS 16 **inertial reference gyro**, and a **standby gyro system.**

Fuel and engine controls

The fuel management system of the VC.10 is designed and made by Elliott (253-4), who are exhibiting the Elliott/Bendix **true mass fuel flowmeter**, the heart of the system. This provides accurate information on mass-flow rate and fuel consumption of each engine. Their auto-throttle is an **automatic throttle control**, which is fed with air-speed and pitch-attitude data, and automatically provides the requisite amount of power.

Bryans Aeroquipment (90) will show the Autotemp, by B & H Instrument (U.S.A.). This instrument provides accurate **measurement of exhaust-gas or turbine-inlet temperature**, using dial and digital indication, over the range 0–1200°C.

To be shown by Lucas Gas Turbine (103) is a **gear-pump** which is one of a range designed to supply engine main fuel for gas turbines. A typical model is the G.P.200 which delivers 200 gal/h at a delivery pressure of 1250 lbf/in². An **integrated fuel system** for helicopters is designed for use with an electronic computer for throttle control. **Main engine controls** to be shown include combined units as fitted to Dart and Orpheus engines, and a range temperature control (Avon and Conway engines).

A variety of equipment to be shown by Dowty (43-8) includes **fuel systems**, an **inlet guide vane control** for the Gyron Junior, and **fuel pumps** and **spill burners.**

Ultra (297) are showing a working model of the remote control of fuel valves by an **electrical servo system**, the BAP3, which is used on the Bristol Britannia, and has had some 2,000,000 flying hours. Two **magnetic amplifiers**, the A605 and A203, are for the automatic control of engine speed and temperature by fuel-trimming; they may be operated continuously at an ambient temperature of 125°C. Another **amplifier**, the A725, is for the detection of irregularities in jet-pipe combustion temperature.

Flowmeters and **indicators** by Negretti & Zambra (160) will be on show. The series 1–4 are designed for use with wide-cut aviation turbine fuels; the series 6 flowmeter is designed for mounting where high fuel-temperatures are encountered. The latter instrument has an accuracy of $\pm 2\%$ of net flow-rate reading in excess of 1000 pounds/h, which is maintained up to 200°C.

An **air/fuel ratio control** for ramjet engines will be shown by H. M. Hobson (165). This automatically controls the fuel supply to the engine so as to maintain a predetermined relationship between fuel-flow and an applied air pressure. A tank-mounted **booster-pump** and canister (specified for the Trident), and a **speed governing fuel-control unit** for pilotless aircraft will also be on show.

Zwicky are displaying two **refuelling units** and two **fuel dispensers** on the outdoor site (Q), and **pressure-control valves**, adjustable **Venturis,** and other components from these systems will be on view on stand 284.

Thermocouples will also be shown by Lodge (16). There are two basic types: standard R.A.E. probes, and more complex turbine entry types. Their **jet-engine igniter** will also be displayed.

In addition to a wide variety of **pumps**, Integral (164) will be exhibiting a transistorized **flowmeter** with a d.c. current output, and a **four channel mass-flowmeter.** This is for measurement of fuel flow through four pipe-lines in a four-engined aircraft, and uses a magnetic rotor to provide impulses whose frequency is proportional to flow-rate. These are fed to a small computer, which incorporates a density correcting circuit.

Southern Instruments (261) are exhibiting the Drayton-Southern Omniguard, an **integrated protection system,** using resistance elements, for large engines and heavy machinery. Bearing temperatures, oil pressures, cooling-water temperatures *etc.*, may all be monitored using a common alarm.

Flight Refuelling (245) will exhibit a wide variety of **fuel-system and refuelling equipment.** Also the Mk 15 **fluid-level switch** designed to have as few moving parts as possible, and a **combined jettison and relief valve.**

Water in turbine fuel can cause difficult problems, particularly icing at high altitudes. Thermal Control (183) are exhibiting the B.P. Aquascan, a **water-content meter** which during refuelling continuously measures the amount of water present in the fuel.

Computation and data-handling

S.T.C. (156-159) are to have an animated display showing the facilities of the Stantec **computing system**; Stantec seat-reservation and aircraft-loading computation systems are being supplied to major airlines. An open display features a simplified wide-aperture **radio direction-finding system**, based on the Doppler principle, which is intended for civil use on secondary airfields.

In the radar display area, Elliott are staging a demonstration of the 803 **computer**, showing its use in aviation applications. Also on show will be a Verdan **airborne digital computer**: this weighs

82 pounds, and occupies less than $1\frac{1}{4}$ ft^3. On stands 253-4 their **multi-channel tape deck** will be on view; this is intended primarily for instrumentation work, particularly in aircraft flight-testing and missile telemetry. The standard model will handle signals up to 70 kc/s at 30 in/s tape-speed.

Thermionic Products (290) will show a number of **recorders**, and are to have a live demonstration of their thermionic **eight-speed data deck** for digital recording.

A **data handling and plotting system**, incorporating a punched-card or perforated-tape translator, curve follow, and a sensitive *X-Y* plotter, will be featured by Bryans Aeroquipment (90). Other exhibits on this stand include a high precision **pressure control and calibration system** for air-data system testing.

A **tabular display** unit to be shown by Marconic (19-23) receives digital information from a data-processing computer and converts this directly into figures on the face of a c.r.t. It is claimed to give an immensely fast display compared with conventional methods of computer-output handling such as teleprinters. They also are showing **closed-circuit television**, now increasingly used in aviation.

Solartron (192) have a **high-speed printer** which will print lines fourteen columns wide at a rate of over ten each second. Their Minispace **computer** will also be on view, and a **digital-data recorder** with an accuracy of 0·1%. This accepts analogue signals of either polarity from up to 50 channels, and converts them into digital form for driving an integral printer. Scanning rate is two channels each second, the printer output giving channel identity, measured signal value, and polarity on a three-inch paper strip. Their **continuously-rotating-drive pressure scanning transducer** sequentially scans a number of non-corrosive gaseous pressures using a single pressure transducer. In this device, a scanning disk, containing a rotating port, runs as a thrust pad against an annular face having a ring of holes near its periphery which lead to the individual pressure inputs. The scanning disk has transfer ports which sample each input pressure in turn so that as pressure equilibrium is established in the sampling chamber a corresponding output is derived from the pressure transducer.

A pictorial display on the Ferranti's stand (184) will show their Apollo **computer for air traffic control**. It is expected that this machine will go into the Scottish Air Traffic Control Centre at Redbrae, Prestwick, later this year.

Servos and actuation

The Elliott (253-4) **clutch-brake unit** allows devices such as synchros and potentiometers to be stopped in any position by remote control, and held securely against vibration or residual torques. A range of **control transmitters** and **transformers** to be shown includes a miniature size-08 synchro, and an electrical two-speed synchro; also a size-11 stub synchro, standard except for a shorter frame which gives a 43% space saving. **Torque motors** in the Elliott range are now available with angular displacement or velocity a.c. pick-offs for feed-back or control use.

Actuators to be exhibited by Rotax (126) include an unusual **three-motor linear actuator**: two are identical 28V d.c. motors, which act as main and auxiliary respectively, and the third motor, operating from 115V, 400c/s, is normally used in conjunction with a servo-mechanism. With either main or auxiliary motors operating, ram speed is 0·086in/s; with the third motor operating, the ram-speed is reduced to 0·0086in/s at the same average load (250 lbf). Also on show will be a **twin-motor rotary actuator**, which automatically switches in the auxiliary motor if the main motor fails, and an **in-line rotary actuator** with a maximum load of 55 lbf in.

Ketay (93) are to show a selection of **synchros, resolvers, precision integrating tacho-generators**, and **servo magnetic amplifiers**. There will also be a new **jet-engine thrust indicator**, and **servo-controlled aerial turning unit**.

On the Wilmot Breeden stand (141) will be Pegasus **servo valves** by Telehoist. Units for aeronautical use have flow capacities from 5 gal/min to 160 gal/min at 3000 lbf/in^2; the largest in this range weighs only 15 ounces. Pegasus **servo-drive systems** are variable-speed drives designed for stability under varying load conditions. They are available with outputs from 1·6 to 6·5 hp, with torques from 160 to 2420 lbf in at speeds up to 1470 rev/min.

Boulton Paul (stand N) are to display a range of sectional models of various aircraft showing their **hydraulic-powered flying control units**. Amongst these is equipment for the VC.10.

Integral (164) have a wide variety of **hydraulic motors, pumps**, and **power packs**, and the type 257 **flow divider**, which divides fuel-flow in any desired ratio irrespective of pressure changes at either outlet, pressure variations, or variations of total flow.

Sperry–Vickers **hydraulic components**, to be seen in three display-areas, include pumps and ancillaries for the DH.121, pumps, motors, and ancillaries for the VC.10, and equipment for the Westland Wessex and Rotodyne *etc*.

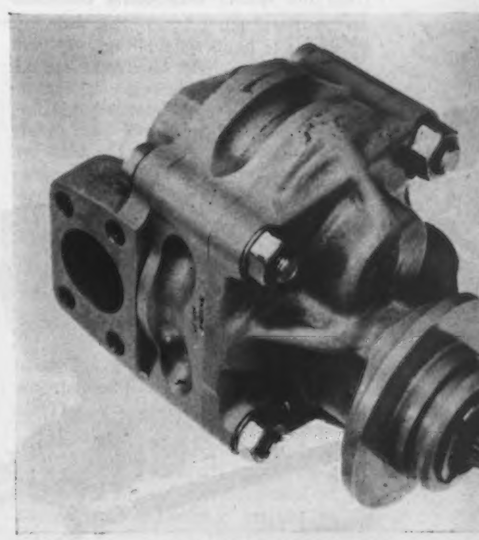
Three **fuel-flow proportioners** will be shown by Hobson (165), all using cycloidal metering rotors. The type 214 **electro-hydraulic actuator**, also to be seen, gives a thrust of up to 1100 lbf at a maximum supply pressure of 3000 lbf/in^2; its response characteristics may be varied from 5 to 50 c/s depending upon drive-amplifier characteristics. Another **actuator** is intended for use in pilotless aircraft. Their **cockpit engine control** is designed to control the two engines in a high-speed fighter aircraft.

Dowty (43-8) are showing a range of **hydraulic pumps, motors**, and **valves**, including the Dowty Moog servo. They will also show equipment for v.t.o.l. and s.t.o.l. aircraft, including **control lift fans**.

Remote controls by Exactor (205) will be on view, including a new **double-acting actuator**. Also on this stand may be seen the Wilkerson **self-drain air cleaner**, for the automatic ejection of water and dirt from compressed-air systems.

Mitchell Hydraulics (111) are to have an interesting demonstration showing a **working assembly of hydraulic servo-valves**. It consists of a ram driving a resistive spring load at the direction of an electrohydraulic single-stage valve, or

Right: The Lucas GP.200 gear-pump for engine main fuel supply
Below: Saunders' solenoid-operated diaphragm valve
Below right: The Omniguard, Southern Instruments' engine protection system



by way of a two-stage servo-valve; in the latter case, input linkage is purely mechanical. As laid out, this demonstration suggests a pilot's contact with his aircraft's control surfaces, and illustrates both electrohydraulic and mechanical closed-loop techniques.

On a combined stand (53-4) Automotive Products and Lockheed Precision Products will be showing equipment for de Havilland's Trident, Folland's Gnat, and the Beagle Executive aircraft. A **hydraulic power pack**, consisting of a miniature electrically driven pump, a self-contained fluid reservoir, accumulator, command switch and selector valve, will also be on view, as will a Gnat **aileron servo**.

Pullin (216) will be showing a range of **instrument motors**, **servo-motors**, **synchros**, and **magnetic and transistor amplifiers**. Another exhibit is a miniature **size-08 d.c. motor**, with an integral gear-box driving a size-08 synchro.

Test equipment

The Honeywell (292) **automatic systems analyser**, selected for R.A.F. service with the English Electric Lightning P.1, is to be shown for the first time. This unit performs the various necessary tests using information stored on punched tape, the testing philosophy on the flight-line being to isolate down to a system 'black box' or the smallest replaceable module. The unit applies proper simulation and switch-closure signals to the system under test, the output signals from the system then being compared with predetermined limits of acceptibility.

An **automatic test console** by Sperry (100) will be seen running through a typical test sequence with corresponding movements of the control surfaces of an actual Seaslug missile. Responses will be displayed pictorially on an oscilloscope and may be recorded on sensitized paper for subsequent analysis.

M.L. Aviation (41) are to exhibit their Mk2 **circuit test unit**, which performs continuity, insulation, and flash-over tests in one operation, or will apply one or more of these tests to any selected individual path in up to fifty different circuits or lines as programmed in the preselector. The automatic selector energizes each path in turn, each step being indicated on a matrix of numbered lamps. An unsatisfactory path stops the selector, the matrix identifies the faulty path, and another lamp indicates the nature of the fault.

Sangamo Weston (72) are to show **ground test sets**, and a representative selection of **indicating instruments** for temperatures, pressure, *etc.*

Two **portable tachometers** will be exhibited by Southern Instruments (251), covering 0–300,000 and 0–30,000 rev/min respectively to an accuracy said to be $\pm 1\%$ f.s.d. Their M 1154 **transistorized counter** is a digital frequency and time interval meter which will measure frequencies from 0·1 c/s to 120 kc/s using counting periods of 0·1, 1·0, or 10s.

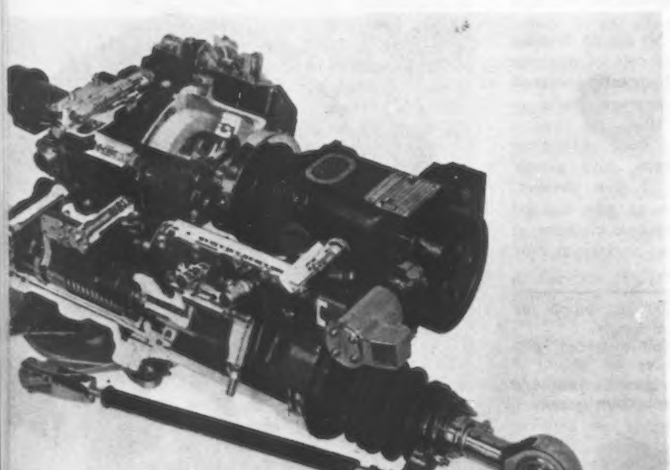
Bryans Aeroquipment (90) are to show a **tachometer tester**, this is a dual stroboscope intended for calibrating engine-speed tachometers and generators, *etc.* It is supplied with a **transistorized tuning fork** which generates a stable 50 c/s frequency for operating the neostron lamps.

On the Venner stand (61) will be recently developed transistorized **airborne and test-bed tachometers**, as well as **digital voltmeters** and **printers**, and examples of their **miniature packaged circuits**.

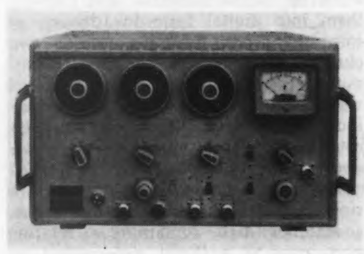
An **electronic calibrator** for testing and calibrating the components of mass or volumetric fuel-flowmeters, either mounted in aircraft or in the workshop, is to be shown by Integral (164). It provides electrical signals of the correct wave-forms, frequencies and amplitudes to enable faults to be localized to any stage of the electronic computer. Also on their stand will be an **expanded range tachometer**, for operating with pick-up equipment such as rotary generators *etc.*

Solartron (192) are exhibiting the GO 1005 **pulse generator**, which provides single or double pulses at repetition rates from 10 c/s to 1 Mc/s, and a double-beam portable **oscilloscope** designed to meet Ministry of Aviation specification K114E.

Two versions of the Pendeford multimeter, a **direct-reading measuring bridge**, are to be shown by Boulton Paul (stand N), together with a range of typical **transducers** for measurement of load, force, and other parameters. Also on the stand will be newly developed **differ-**



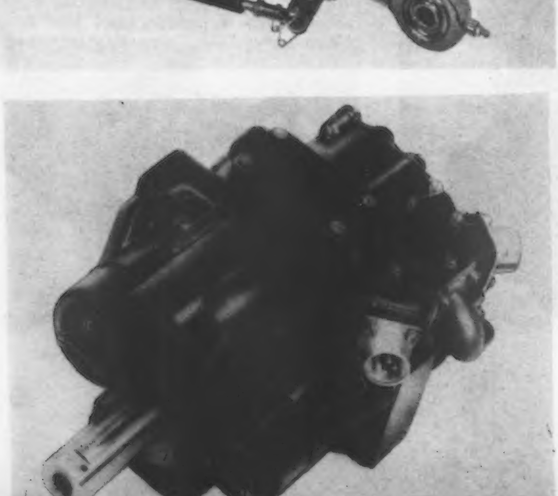
Left: A hydraulically operated aileron control unit by Boulton Paul



Above: Solartron's 10c/s-1Mc/s pulse generator, the GO.1005

Below left: A three-motor linear actuator by Rotax

Below: Honeywell's automatic systems analyser in use with a U.S. Starfighter



ential inductance pick-offs which will work at up to 500°C and are immune to nuclear radiation.

Graseby Instruments (179) have a range of **gyroscopic test equipment**, including a **servoed gimbal universal tester** with automatic photo-electric read-out; also on show will be **accelerometers** and an **accelerometer recorder**.

Cossor (240-1) will be showing the FT.13B **automatic field test-set**, with which a semi-skilled operator can rapidly check an aircraft v.o.r./i.l.s. system. The FT.17 provides more comprehensive facilities than the FT.13B, and is fully transistorized. Also on show will be the Convolt, a **stabilized power-supply** which gives a nominal 1V output with a temperature coefficient of 0·001%/degC, and a voltage stability such that a 10% change in input voltage causes a change of output of only 0·001%. Oscilloscopes to be seen include the 1063A, a long-persistence model intended for use with a range of transducers for dynamic pressure measurement.

Telemetry

W. S. Electronics (271) are to show a multi-channel **v.h.f. telemetry transmitter**, type D145, which is to be used in target aircraft. Also to be seen is their two-box v.h.f. telemetry transmitter, which forms part of the R.A.E. telemetry sysem.

The Meteor U. Mk 16 **pilotless target aircraft**, developed and built by Flight Refuelling (245), will be exhibited statically for the first time. Where possible, Perspex panels are fitted to allow command and control equipment to be viewed.

Airtech (open site X) will be exhibiting elements of recent developments in telemetry, a fully transistorized **demultiplexing and data handling equipment** for use in air-to-ground systems. Also to be seen are various airborne units, including a **drone control frequency-selector unit**.

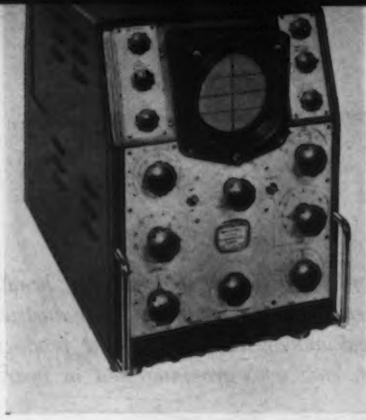
A transistorized **data transmission system** by G.E.C. (33) consists of a ground-to-ground digital data link, and an airborne digital-to-analogue converter unit. The ground link uses three standard land-lines, and achieves information rates up to 3600 bauds. After conversion in the airborne unit from digital to analogue form, the instructions to the aircraft can either be displayed on suitable instruments or coupled directly into the autopilot.

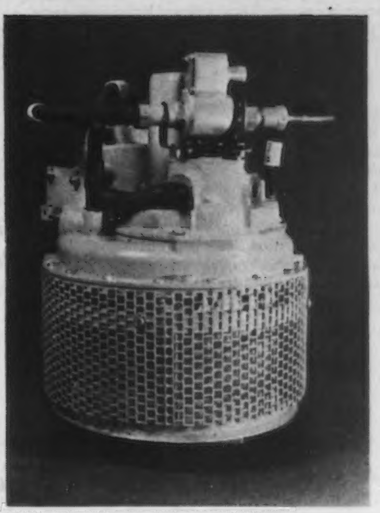
Beme Telecommunications (80) are to show **encapsulated voltage telemetry units**, and **destroy and control receivers** for guided weapon applications.

R.A.E. (covered stand 2) are to contribute a **rocket-launched free-flight model** in the Apollo series. Normally launched at about 1200 miles/h, data on drag, dynamic stability and aerodynamic heating is relayed to the ground by radio-telemetry equipment in the body.

Air and temperature control

A wide range of **pressurization, air-conditioning** and **oxygen breathing equipment** will be displayed by Normalair (227-9). Shown for the first time at Farnborough will be the Transall C160 two-speed Calsin **air compressor**, and two units for the VC.10: an electropneumatic **pressure control equipment**, and a **vapour-cycle cooling pack**. The pressure control unit is actuated electro-pneumatically, obviating the need for long pneumatic pipe runs by using electric signals to control pneumatic discharge valves.





Above: A pneumatic discharge valve by Normalair
Above left: Cossor's 1049, Mk IV, oscilloscope for electromechanical phenomena
Below left: Hymatic's PAS.217 butterfly reducing valve

Teddington Aircraft Controls (49) are to have a display panel showing equipment for the VC.10, also complete **air-conditioning and pressurization equipment**, and a range of **flow controls** and **non-return valves**. The scope of the Teddington display is enhanced by equipment from the French S.E.M.C.A. organization, with whom an agreement has been recently completed, and whose **gas turbine starter** will be on show.

Systems are emphasized by Hymatic (273), who cover fuel pressurization, anti-*g*, radome, and air-ventilated suits. A range of **butterfly valves** for high temperature operation includes a **three-inch valve** which will perform either as stop-valve—giving on–off control—or as a modulating valve controlling to a set downstream pressure. Extreme conditions are catered for by pressure reducing and solenoid valves for temperatures of 400°C, 400 ft^3/min flows, and pressure to 4500 lbf/in^2. Also on show will be a **vent valve** designed for use in fuel pressurization systems.

Sir George Godfrey's (31) main exhibit is a **gear-box compressor**, four of which are used to provide the charge air for the pressurization and air-conditioning system of the VC.10. Automatic proportional control of the air mass flow delivered by the compressors is regulated by two electropneumatic mass flow controllers, type FC.10, each of which monitors the positions of hydraulically operated valves on a pair of compressors.

Five **blowers** for the VC.10 are to be exhibited by Plannair (217). The largest of these is an 8in diameter axial-flow unit, incorporating an integral sound-deadening device, which is fitted to the cabin-air recirculation system.

Guided weapons

On show this year for the first time, on the Hawker Siddeley stand (L), will be the de Havilland **Red Top**, an infra-red-homing air-to-air missile. In the guided weapons park are the de Havilland **Firestreak**—also air-to-air infra-red—as fitted to the Javelin, Lightning, and Sea Vixen; the Avro **Blue Steel** air-to-ground stand-off bomb, for the R.A.F.'s V-bombers; and the A.W.A. **Seaslug**, guidance and control of which are by G.E.C. and Sperry.

The Bristol–Ferranti **Bloodhound**, a semi-active-homing, surface-to-air device, will be on show once more.

English Electric's **Blue Water** surface-to-surface missile will be exhibited, as will their semi-active-homing, ground-to-air **Thunderbird**.

Short's **Seacat** ship-to-air weapon will be on show, with its associated launcher and director; on their main stand (I) will be a one-tenth scale model of the **Seacat II**, a supersonic version of the original.

A new weapon by Vickers, the **Vigilant**, is a wire-controlled anti-tank weapon with a range from 200 to about 1500yd. The great advantage claimed for this device is that it does not require a highly-trained operator to fire it accurately.

The Ministry of Aviation (covered stand 2) are to show a model of the projected Anglo-French **satellite launcher**, which is to use de Havilland's **Blue Streak** as its first stage, the second stage to be provided by the French.

A monthly review—under basic headings—of the latest control engineering developments for all industries; especially edited for busy technical management, plant and production engineers, chemical engineers, etc., who are interested in instruments and control systems.

IDEAS APPLIED ...

... to FLOW

Controlled-rotor flowmeter

The popular 'propeller' type of flowmeter suffers from the disadvantage that variation of the frictional forces acting on the rotor during service impair its accuracy. This is particularly true where little power is available to drive the rotor, as when measuring small gas flows. As bearing wear is a major cause of variable friction, most of the recent development work on this class of meter has been directed at improving the bearings. (Examples are the thrust-relief system used in the Pottermeter, and the fluid bearings being developed by N.E.L.)

A new approach to the problem is being made by Gaz de France (*1*), with the particular object of producing meters for small flow rates which will function for long periods without maintenance. The principle used is, basically, to control the rotor to a speed which is below its maximum, but which is accurately related to the volume of gas passing. The elements of the system are shown in Fig. 1.1. Gas passes through a set of fixed guide blades *A* and drives the rotor *B*, which is mechanically connected to an external counter. *A* and *B* are similar in design to the fixed and rotating blades of a gas turbine. The purpose of the third set of blades, *C*, which are parallel to the axis of rotation, is to produce a controlled braking effect on *B*.

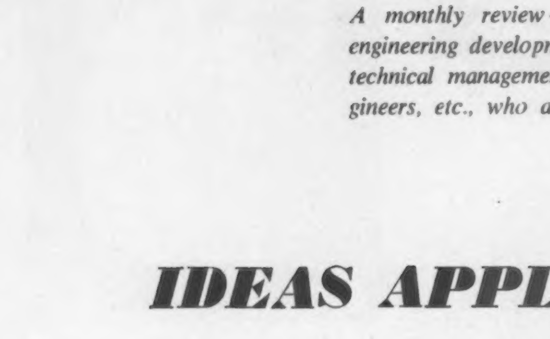


Fig. 1.1 'Maximum efficiency' propeller-type flowmeter. Rotor B is constrained to rotate at the speed corresponding to purely axial velocity of the fluid leaving it. If this fluid velocity has a tangential component, the control rotor C is turned, and eddy current braking of the aluminium disk is adjusted

The rotor *B* is controlled to run at the speed at which the gas leaving it has a purely axial velocity. Any tangential component of this velocity causes *C* to turn, modifying the braking effect on *B* to restore axial flow. This axial flow condition corresponds to the maximum power output from *B* for a given speed of rotation. For this reason, the new meter has been referred to as the 'maximum-efficiency propeller-type meter'.

It will be appreciated that, if the gas flow leaving *B* is purely axial, the speed of rotation of *B* is unique for a given volumetric flow of gas. As the rotor is being continuously braked by the feedback system, changes in frictional loads within reasonable limits will not affect its accuracy. Apart from a small deviation at very low velocities, the speed of rotation/flow curve for the meter is a straight line through the origin.

The feedback braking is accomplished by eddy currents, the rotor *B* carrying an aluminium disk, and the 'control' rotor *C* adjusting the clearance between the disk and permanent magnets. These magnets are mounted inside the hub of the control rotor, and are positioned by a gearing and leadscrew arrangement.

In addition to the laboratory model described in Ref. *1*, two industrial prototypes have now been made and are undergoing tests.

Reference
1. D. Souriau: 'Recherches sur les compteurs à moulinet. Le moulinet à rendement maximum'. Paper read at the 1960 Congress of l'Association Technique de l'Industrie du Gaz en France.

Development of 'gate' type meters

The principle of the 'gate' flowmeter, in which the angular displacement of a hinged flap by the metered fluid is used as a measure of flow rate, is well known. The flap is usually installed in a horizontal length of pipe and pivots about its top edge, turning a shaft which passes through glands and drives an external indicating mechanism. In the conventional form of meter, the restoring force on the flap is provided by its own weight. Such

meters are characterized by high sensitivity for small openings of the flap, with decreasing sensitivity as the opening increases. Because of this change in sensitivity, and more particularly because of the need for glands which must produce little friction, gate meters have so far found few applications. Their main use has been on water lines where the normal flow is small, but where abnormal high flow rates occur on rare occasions.

New types of gate meter have been developed at A.E.R.E. Wantage to overcome these disadvantages (2). The use of glands has been avoided by fixing a radio-active source to the gate and determining its position by an external detector, and the meter characteristic has been changed by adopting a multiple-gate system. The experimental meters which have been made at Wantage have been intended for measuring small gas flows, and have used a 1in-diameter pipe.

Fig. 2.1 shows the first stage of the development, using a single gate with a radio-active source attached to its lower edge, and a radiation detector mounted on the top of the pipe. With this arrangement, a near-linear relation can be obtained between rate of flow and the dose rate falling on the detector, over a relatively wide flow range. The authors (2) have found that the most satisfactory detectors for this application are cadmium sulphide single crystals, since they can be operated by a simple circuit consisting of only a h.t. battery and a current meter.

The second stage of the development is the introduction of the 'combination' gate to extend the operating range. Alternative forms of combination gate are shown in Fig. 2.2. Both forms consist of a series of gates of differing areas but turning about a common axis, each gate being smaller in area than the gate on its downstream side. Gates which do not completely cover the aperture have a definite flow 'threshold' below which they do not move, and thereafter lag

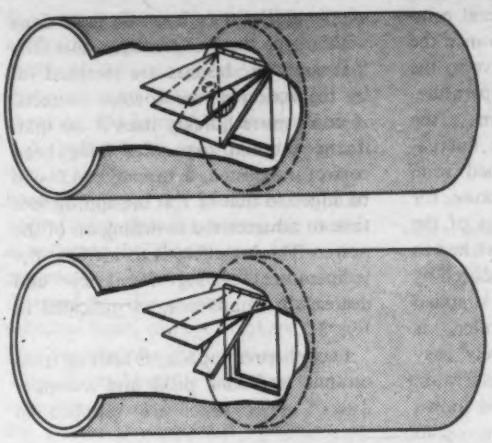


Fig. 2.2 Alternative forms of combination gate. Top left: different gate areas obtained by orifices cut in the gates. Below left: gates of different widths. With either arrangement, each gate carries a radio-active source attached to its lower edge, and the output is taken from a suitably placed radiation detector

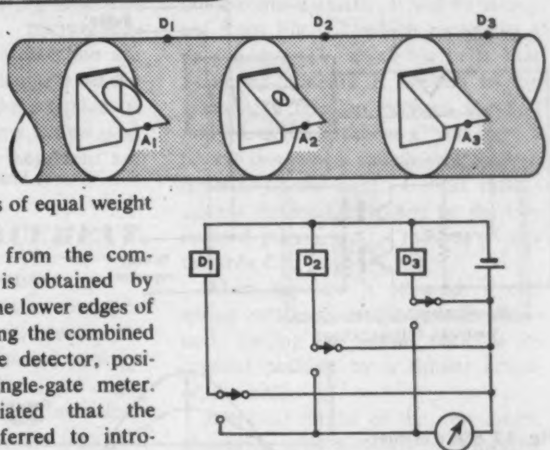


Fig. 2.3 Cascade gate system and detector circuit for wide-range flow measurement. A_1, A_2, A_3 are radio-active sources; D_1, D_2, D_3 are radiation detectors

behind the larger gates of equal weight as the flow increases.

The output signal from the combination-gate meter is obtained by attaching sources to the lower edges of each gate and detecting the combined dose rate by a single detector, positioned as for the single-gate meter. It will be appreciated that the 'threshold' effect referred to introduces discontinuities in the response. A further difficulty arises with certain gate combinations, in that discontinuities in the response do not occur at the same flow rate for increasing and decreasing flows. It has been found, however, that a satisfactory response can be obtained with a two-gate combination, if the weights of the gates and the strengths of the sources are correctly chosen. In general, the lower gate requires to be heavier, and to carry a stronger source.

The combination gate, using a number of gates on a common hinge, has the advantage of being compact. If a number of gates dispersed along the line can be tolerated, each with its own detector, the arrangement of Fig. 2.3 can be used to cover a wide flow range. In this arrangement, the gate weights and areas are designed to give good response over different portions of the flow range, the appropriate detector being switched in series with the flow indicator at any given time. If cadmium sulphide crystals are used as detectors in this arrangement, the switching has to be arranged so that a voltage is continuously applied to each crystal. A further multi-detector arrangement, suggested for flow control applications using a single gate, uses and additional detector D_2 (Fig. 2.1). The output from D_2 is highly sensitive to small changes in gate position, particularly for low flow rates.

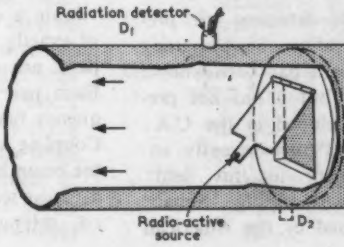


Fig. 2.1 Gate meter using a radiation detector (D_1) to determine gate position. A radio-active source is attached to the lower edge of the gate

Reference

2. Clayton, C. G. and Webb, J. W: 'The Continuous Measurement of Gas Flow using a Hinged Gate and a Radioactive Source', *Use of Radioisotopes in the Physical Sciences and Industry*, 1 (I.A.E.A., Vienna, 1961) p. 499

. . . to TEMPERATURE

Improved two-step control

Various thermal lag devices have been produced recently, with a view to improving the performance of two-step control systems. Most of these have been intended primarily for temperature

control applications. The general principle of such devices is to advance the 'on-off' switching cycle relative to the cycling of the controlled temperature. The effect of this is to decrease the amplitude of the temperature fluctuations. The idea has not gained wide acceptance so far, possibly because, for good results, the characteristics of the lag device must be correctly matched to those of the plant. A unit introduced by Hartmann and Braun, and supplied separately from the controller, is designed to allow for relatively easy adjustment of its thermal characteristics.

The principle of the device is shown in Fig. 3.1. Two similar thermocouples, *A* and *B*, are connected in opposition across the resistance *R*. A proportion of any potential drop across *R* is fed into the main measuring circuit, in series with the output from the measuring thermocouple *T*. *A* and *B* are built into thermal capacities, which are simultaneously heated, by similar heating elements, during the 'on' part of the switching cycle. The thermal capacity of the '*A*' element is less than that of the '*B*' element. Thus, during a heating-up period, the temperature of *A* will rise quicker than that of *B*. This has the effect of adding a small e.m.f. to the output of *T*, so that the e.m.f. fed to the controller corresponds to a temperature above the true value. The controller therefore operates, switching off the supply earlier than it would have done without the thermal feedback unit. The '*A*' and '*B*' heaters are switched off by the action of the control contacts. *A* cools more quickly than *B*, so that, if the thermal capacities have been correctly adjusted, a reverse e.m.f. will be added to that of *T* at the appropriate time to advance the switching-on of the power. The net effect is to increase the temperature cycling frequency and decrease its amplitude, as indicated in Fig. 3.2.

Each thermal capacity is built up from ceramic insulating disks and a copper disk. Copper disks are supplied in various thicknesses, and can be easily changed. Thus the time constants of the two capacities can be adjusted independently. This adjustment, and the adjustment of *R*, permit the user to match the characteristics of the feedback unit to those of the plant.

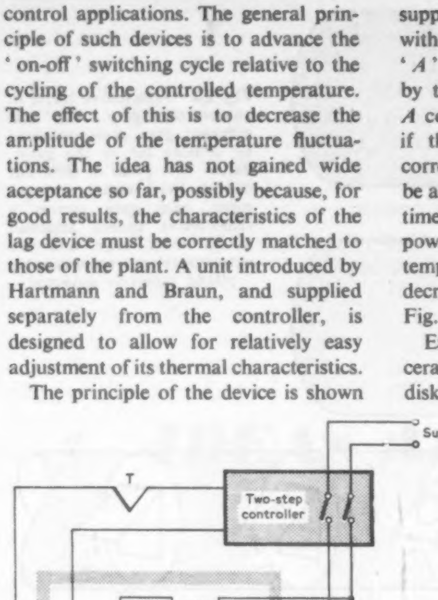


Fig. 3.1 Use of thermal feedback to improve two-step control

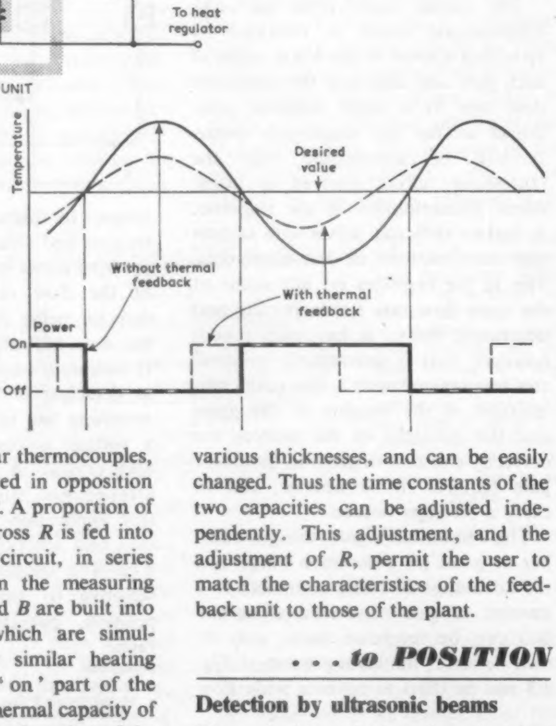


Fig. 3.2 Effect of thermal feedback on two-step control. Rate of cycling is increased, and amplitude of the temperature fluctuations decreased

. . . to POSITION

Detection by ultrasonic beams

The principle of detecting the presence or position of an object by using an ultrasonic beam has been known for many years, but it has not previously been developed in the U.K. Two British firms have recently announced equipment in this field: Westool, who will supply 'Sonac' equipment designed by the American Delavan company, and Elcontrol, whose 'Sonotek' equipment is of their own design and manufacture.

Fig. 4.1 Westool ultrasonic equipment, showing heads fitted with focusing reflectors

Most of the applications of these ultrasonic systems are of the type at present covered by photo-electric devices. The general principle is similar, in that a beam of energy is directed from a source to a receiver, either directly or along a reflected path. Ultrasonic equipment has important advantages in some of the applications where light-operated equipment is at present used, and opens up new possibilities in the field of detection.

The main advantages of ultrasonic detection systems over photo-electric systems are: (1) the transmitters and receivers are normally unaffected by dirt; (2) they are unaffected by changes in ambient light; (3) transparent materials and surfaces may be detected; (4) the use of reflected beams is more practicable than with a light beam, as almost any solid or liquid surface will reflect satisfactorily; (5) the transmitters and receivers can be remote from the surface being detected, the ultrasonic waves being 'piped' in small bore tubes to the required positions.

Equipment

Details of the construction of the transmitting and receiving heads are not at present available for either of the two systems. We are told that the Westool transmitter works on a magnetostrictive principle, the length variation of a nickel rod in an alternating magnetic field being used to vibrate a diaphragm. The receiver is of exactly similar design, and the two parts are supplied as matched pairs. Each pair operates in a narrow frequency band in the range 37–39 kc/s. Coupling devices are available when the beam has to be 'piped', to reduce its cross-sectional area to that of ¼ in i.d. tubing. The maximum recom-

mended length of such tubing is 6 ft for each unit. If no special focusing devices are used, the beam spreads at a wide angle (about 50°) from the transmitter. Satisfactory operation is obtained in most applications for beam-lengths of up to 20 ft. For longer beams, or where narrower beams are specifically required, focusing is possible by means of parabolic reflectors attached to the heads (see Fig. 4.1).

In the Elcontrol system, the two heads are again of similar construction, but the magnetostrictive principle is not used. The transmitter and receiver are not highly tuned and can be replaced individually; the use of

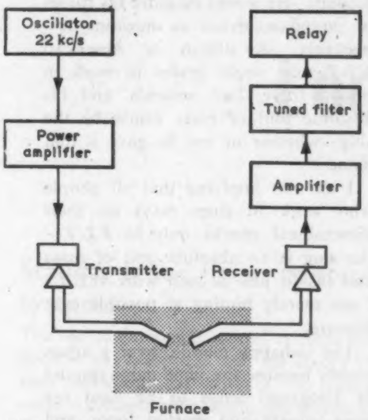


Fig. 4.2 Block diagram of Elcontrol equipment used for flame detection

untuned units has the advantage that the system continues to work satisfactorily even if the temperatures of transmitter and receiver are widely different. As the operating frequency (22 kc/s) is only just in the ultrasonic region, a high-pass filter is included in the receiving equipment to prevent interference by ambient noise. The maximum beam length in free air is 6 ft, but up to 10 ft of smooth bore piping may be used with each head, allowing a total separation of up to 26 ft.

Applications

Ultrasonic detectors are suitable for most applications where photo-electric detectors are currently used, with the advantages already mentioned. Surprising sensitivity to position may be achieved in reflected-wave arrangements. One such application has been demonstrated by Westool, where articles on a conveyor belt were being checked for orientation. The beam was directed by a short length of piping at the plane top surface of the articles, and received *via* a similar short guide pipe suitably positioned to accept the reflected beam. The sensitivity of this arrangement suggested that it might have applications in checking the level in filled containers.

A particularly interesting application in the field of flame detection has been developed by Elcontrol. It has been found that the ultrasonic beam is reflected by flame, and hence the presence or absence of flame can be detected by this means. Further, the reflected beam always 'flickers', however steady the flame may appear. Thus, by making the receiving circuits responsive to modulation of the beam, the system is unaffected by reflection from solid surfaces. Transmitted-beam systems for flame detection are also being developed. Elcontrol believe that the discovery of the reflexion of ultrasonic waves by flame is new, and patents covering the arrangement are pending.

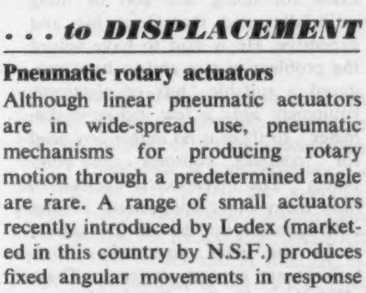
. . . to DISPLACEMENT

Pneumatic rotary actuators

Although linear pneumatic actuators are in wide-spread use, pneumatic mechanisms for producing rotary motion through a predetermined angle are rare. A range of small actuators recently introduced by Ledex (marketed in this country by N.S.F.) produces fixed angular movements in response to an air signal, using a relatively simple mechanism.

Rotary motion is derived from the linear motion of a piston by means of a system of steel balls running on inclined planes. The principle of this system can be seen from Figs. 5.1 and 5.2. Air pressure is applied to one side of the piston *A*, and the load is transmitted to the driven member *C* *via* the balls *B*. *C* is prevented from moving axially by the thrust bearing *D*, but is free to rotate, whereas *A* is prevented from rotating by the guide pins *E*,

Fig. 5.1 Schematic section of actuator



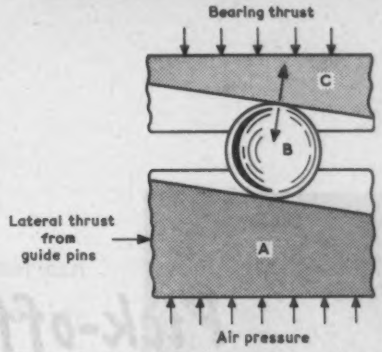


Fig. 5.2 Principle of conversion from linear to rotary motion

but can move axially. It will be apparent from Fig. 5.2, which represents a section through one of the balls, that when air pressure is applied to the piston, the reaction between the ball and the driven member *C* will have a lateral component which will tend to drive *C* to the right. *C* thus rotates against the load, *B* rolling on the two inclined planes, and *A* moving axially towards *C*.

When pressure is released, a coil spring rotates *C* in the reverse direction, forcing the piston back to its original position by a similar action of the balls.

A typical model of the new range, measuring approximately 1½ in long by 2 in diameter, gives a starting torque

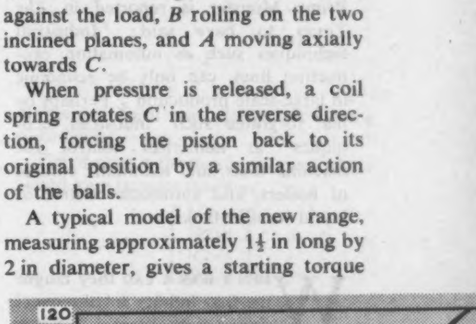


Fig. 5.3 Relation between starting torques and input air pressure

of 6·5 lbf in for an input pressure of 120 lbf/in². Operating time depends on the load, but at no load and using maximum pressure, it is claimed to be 30–40 ms for a 90° rotation. Starting torque varies linearly with air pressure, as shown in Fig. 5.3.

The design is the subject of U.K. patent applications.

Pick-off

by 'UNCONTROLLED'

DURING ONE of his speeches on Britain's application for admission to the E.E.C., the Prime Minister is reported in *The Times* to have said: 'Industrial techniques such as automation production lines, can only be economic in large-scale production'. Perhaps he had forgotten such 'industrial techniques' as numerical control for machine tools, and automatic control of boilers, and automatic control of liquid level in tanks, and . . . .

WHEN I WAS A LAD they taught me that infinity (of the over-tipped-eight kind) is greater than any number you can name. An announcement has just reached me from the States, however, which gives me pause. It is about a time-delay device. The instrument is stated to have a range from milliseconds to infinity, and the accuracy is claimed to be '0·01%'. Does this mean $\pm 0{\cdot}01\%$ of the set time? If the mathematicians are right, and ∞/n is the same as ∞ for finite n, then the device must presumably become more inaccurate than anything you can name. Perhaps it is as well that salesmen are not mathematicians.

HERE IS SOME MORE transatlantic news that may be worth pondering. A press release describes as 'a revolutionary idea' 'the invention of an American electronics expert, Mr Royal O'Reilly, who worked for a time in Alaska on the Dewline early warning system'. Mr O'Reilly and his friends apparently used to spend their off-duty time watching the Aurora Borealis while they listened to gramophone records, which they found 'unusually soothing or stimulating depending upon the music and the colour combinations'. Mr O'Reilly knew that equipment exists for doing this sort of thing artificially, and that it is big and expensive. He is said to have solved the problem of size and to have produced a suitable 'box of electronic equipment only a few inches in diameter', so there is no longer any need for 'complex consoles and computers'. The invention is claimed to have many other applications besides entertainment, but the one that should make you prick your ears up is 'supersonic control devices'. These will 'automatically open garage doors, or operate burglar alarm systems'. Imaginative readers will no doubt see other possibilities also.

SOMETIMES, when I become a bit destructive on this page, I do so because I hope to provoke discussion of important topics. Disappointingly, my depth charges often sink without trace. But an innocent remark I made in last December's *Pick-off* seems to have set off an astonishing number of letters to the Editor.* My contention was that the use of absolute units in dynamics avoids trouble with g, but apparently not everybody agrees. For what it is worth, my view of the matter is this. By using absolute units we cut out the factor of proportionality and are enabled to write inertial (or resultant) force equal to mass times acceleration. The only question then is: which absolute units? There is not much worry about the acceleration term, which is in dimensions of L/T^2; standards of length and time are preserved by the appropriate authorities. The difficulty is that the appropriate authorities also preserve certain lumps of matter that can be taken to define either the unit of mass or the unit of force. If you like working in M,L,T dimensions you may say that the lump has unit mass. The absolute unit of force is then derived, for the gravitational force on the standard lump must be g units. If you prefer F,L,T dimensions you may say that the lump has unit weight. Then the absolute unit of mass is derived, because the mass of the lump must be $1/g$ units. In other words, an M,L,T man might use pounds-mass, feet, seconds; or grams, centimetres, seconds; or kilograms, metres, seconds. He would measure his forces in poundals, dynes or newtons respectively. A British or American F,L,T man might prefer to work in pounds-force, feet, seconds, and his absolute unit of mass would be the slug—whether or not he gave it that name.

I am not implying that all people who work in slugs (say) do their dimensional checks only in F,L,T—the slug is an absolute unit of mass and fits in just as well with M,L,T: I am merely hinting at possible case histories.

The unhappy muddle over g arises mostly because the same name (pound or kilogram) tends to be used for mass, weight and inertial force, and their proportionality makes it easy to forget the differences between them. Personally, I still find it a remarkable fact that the gravitational attraction between bodies depends on the same property (mass) that determines their individual resistances to acceleration.

THE NEW STRUCTURE of the Institution of Electrical Engineers is, at least superficially, less respectful than ever to the control engineer. It seems to me that the only senior professional body now giving proper recognition to automatic control is the Institution of Mechanical Engineers, which reserves one of its new horizontal groups for the subject. I suppose that this is fair enough really, because the theory is undoubtedly dynamic in character and probably should move into what the mechanical engineer calls the Theory of Machines. The use of electricity in machinery, however wide-spread, is incidental. But it is disappointing to see the I.E.E. lose so much of its interest because undoubtedly the electrical (or should I say 'electronic'?) hardware is playing a predominating part in control systems.

* The latest appear on p. 84 in this issue.—EDITOR

This month's contribution from our American correspondents discusses the problem of standardizing performance specifications of linear automatic control systems

Look at America

Standards for linear control systems

The use of automatic control systems has become so widespread, and the theory of their behaviour (at least of the linear variety) so universally taught and accepted, that standardization of performance specifications for these systems may well serve a useful purpose at this point in the history of their development. In a paper by Gibson, Rekasius, McVey, Sridhar, and Leedham (*1*) the results of an extensive study of this question are presented in the form of a recommended set of specification standards. These fall into three classifications: frequency domain, time domain, and generalized performance indices, from which a non-conflicting set of criteria is evolved. All the specifications have in common the fact that they are defined on an input signal *v.* output signal basis, hence the specifications in no way dictate design procedures for a given component.

The linear systems under consideration here are those that can be described by linear differential equations with constant coefficients. A system can be proved linear if it is shown that the principle of superposition holds for it, but in any practical situation this criterion cannot be directly applied, because all real physical systems will become noticeably non-linear for sufficiently small or sufficiently large inputs. For the purpose of setting specifications then, a system will be considered linear if its response lies within the tolerances placed upon the linear specifications recommended for its idealized (linearized) mathematical model, and in addition, the range of magnitudes of the various types of input signals must be specified.

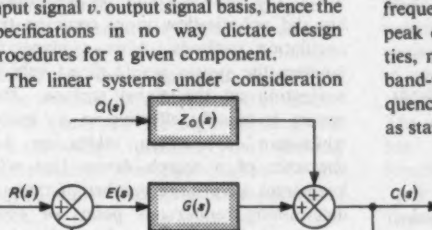


Fig. 1 Generalized system with load disturbance

Fig. 1 shows the generalized system being considered, and defines the important quantities involved. $R(s)$ is the reference input, $E(s)$ the system error, $C(s)$ the controlled output, and $Q(s)$ the load disturbance.

Frequency domain specifications

In this area of system behaviour four quantities were judged to be of greatest importance: (1) *M*-peak, M_p; (2) peak frequency, ω_p; (3) band-width, *BW*; (4) peak output impedance, Z_p. Other quantities, notably gain and phase margin, gain band-width product, and cross-over frequency were considered, but not accepted as standards. The recommended manner of presenting closed loop frequency response data is shown in Fig. 2, which also defines the quantities M_p, ω_p, and *BW*. The 'box' which encloses the actual frequency response represents the admissible tolerance according to the specifications. It is noted that the system response is presented in normalized form and plotted on log–log co-ordinates.

The *M*-peak is the maximum value of the closed loop transfer function,

$$M_p = \left[\frac{\dfrac{|C(s)|}{|R(s)|}}{\dfrac{|C(o)|}{|R(o)|}} \right]_{\substack{\text{max.} \\ s=j\omega}}$$

It is used mainly as a relative stability criterion to prevent a system from amplifying any particular frequency component to a dangerous level. Peak frequency, ω_p, is the frequency at which *M*-peak occurs. This is not to be confused with the resonant frequency which is defined as the frequency at which the output is in phase with the input. Since band-width is a term more directly related to filter design, its application to control systems is not always clear. Here it is defined as the range of frequencies between zero and the frequency at which the closed loop transfer function has the magnitude of 0·707 of its zero-frequency amplitude (or 3dB down). The use of a band-width specification ensures that a system will be able to follow its expected inputs effectively.

Loading effects on a servo-system are defined in terms of the output impedance,

$$Z(j\omega) = \frac{C(j\omega)}{Q(j\omega)}.$$

For instrument servos, where loading effects are negligible, a value for $Z(j\omega)$ is not required. However, in systems where the servo must drive a heavy load, it is important to ensure that the effects of the load itself, or changes in the load, do not cause stability problems. Specifying a peak value of $Z(j\omega)$, Z_p, prevents such a situation.

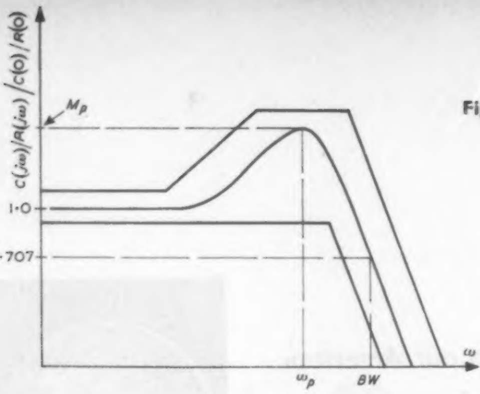


Fig. 2 Frequency response enclosure diagram

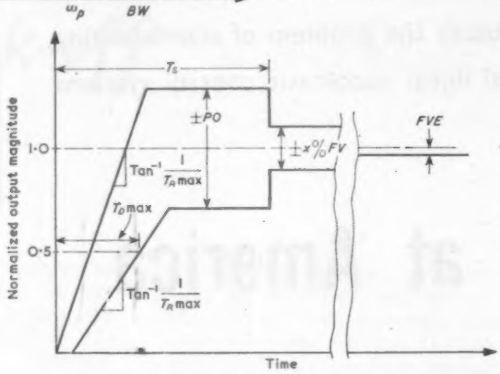


Fig. 3 Recommended specifications for time domain behaviour

Time domain specifications

The quantities recommended to specify the time domain behaviour of a system are: (1) delay time, T_D; (2) rise time, T_R; (3) settling time, T_S; (4) percentage overshoot, PO; (5) final value of error, FVE. These quantities are all defined in Fig. 3 where again it is seen that a 'box' in the time domain is formed by the specified values of these quantities and their tolerances. In all cases, the system response, $C(t)$, must lie inside the box when $R(t)$ undergoes a step change.

T_D is defined as the time which elapses before the *average* output reaches one-half its final value, and T_R is defined as the projection on the time axis of that part of the tangent to the *average* response curve, at $t = T_D$, which lies between zero and the final value. The word 'average' must be included here to make the definitions workable for higher order, oscillatory, systems. The average response is obtained by drawing the best smooth curve through the actual response.

The settling time, T_S, and percentage overshoot, PO, are concerned with how fast the transient part of the response will fall within a given tolerance. For second order systems a quantity such as ζ, the damping ratio, is adequate for this purpose, but in higher-order systems it loses its meaning. T_S is defined as the time which elapses before the response of a system falls to, and remains within, $\pm x\%$ of its final value, x being specified for each particular system.

Percentage overshoot is defined as

$$PO = \frac{(\text{max. value of response—final value})}{\text{final value}}$$

By specifying a value for T_S, it is guaranteed that the effects of the transient will be unimportant after a desired time; by specifying a value for PO, it is ensured that the amplitude of the transient is not too great.

The final value of error, FVE, is defined as $\epsilon_{ss} = \lim_{t\to\infty} [\epsilon(t)] = \lim_{s\to 0} [s\epsilon(s)]$ where ϵ_{ss} is the steady state error. Specifying a value of FVE ensures that the system will be statically accurate.

Generalized performance indices

A generalized performance index is some mathematical function of a system's measured response which sums up, in the form of a number, the overall system behaviour as described by the foregoing specifications. This one number can be used as a figure of merit, to rate a system's performance. Thus far it does not seem possible to recommend any index for general use, although there are certain indices that show some promise when used with special classes of systems. These are:

$$\int_0^\infty t|\epsilon(t)|\,dt, \qquad \int_0^\infty t\epsilon^2(t)\,dt, \qquad \int_0^\infty t^2\epsilon^2(t)\,dt,$$

$$\text{and} \int_0^\infty t^2|\epsilon(t)|\,dt.$$

Another criterion which is not recommended for specification is statistical optimization by means of minimizing the mean square error. Several reasons are advanced for not including this criterion, one of the most important being that it is doubtful whether a system optimized by minimizing its mean square error is really the 'best' system. It is well known that the mean square error is chosen to be minimized mainly because of the mathematical convenience involved, and not so much because it is the best known error criterion. Another drawback to this technique is that the attendant analysis requires the inputs to be both stationary and ergodic. In practice stationary inputs frequently do not exist and also it would be extremely difficult to show whether or not the ergodic condition was being met.

In conclusion, it is stated that the quantities recommended as specification standards: M_p, ω_p, BW, Z_p, T_D, T_R, T_S, PO, and FVE are an adequate and non-conflicting set that will allow a convenient description of desired system performance.

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Reference

[1] Gibson, J. E., Rekasius, Z. V., McVey, E. S., Sridhar, R., and Leedham, C. D.: 'A Set of Standard Specifications for Linear Automatic Control Systems', *Transactions A.I.E.E.*, pt II Application and Industry, 1961, *54*, (May), p. 65

Interplanetary navigation

In a paper entitled 'A Self-Contained System for Interplanetary Navigation', presented in San Francisco at the annual West Coast meeting of the American Astronautical Society on 3 August, R. I. Lillestrand and J. E. Carroll of Control Data Corp. described a system in which a special wide-angle camera, mounted in a space vehicle, could record the time of appearance and disappearance of celestial bodies through precisely positioned slits in the camera's focal plane. Coupled with a miniature on-board digital computer which is now under development, the system would provide a single instrument that could be used under program control in a wide variety of navigational applications. For example, a space vehicle's attitude could be determined and controlled to provide optimal viewing of the moon. The authors describe a statistical technique called 'least squares polyangulation', by which the vehicle could be positioned, but did not disallow more common triangulation methods. After a planetary landing, the system would direct vehicle navigation on the planet surface. The system is equally effective in a 'track-while-scan' application, taking on the character of a search device that will keep track of a large number of targets, determining rendezvous points or controlling impact avoidance for navigation through an asteroid belt.

The Control Data computer is claimed to be of high reliability and extremely small in size and weight. It is designed to satisfy the reliability requirements of unattended operation for over one year, which is considered to be an average time for interplanetary travel.

CONTROL IN ACTION

Month by month—reports from the field

Magnetic drum controls register-translator

Data handling in telephone subscriber trunk dialling

by **W. A. C. HEMMINGS** *and* **W. H. FILES**

Automatic Telephone and Electric Co. Ltd

THE INTRODUCTION OF SUBSCRIBER trunk dialling (s.t.d.) will enable telephone subscribers to establish trunk calls without the intervention of an operator. Every subscriber will be given a 'national number' made up of the local number prefixed by up to five digits for national identification purposes. The national number is itself prefixed with the digit '0', which gives access to the s.t.d. equipment.

The routing to a particular exchange from any other exchange depends upon the location of the originating exchange, and so the originating subscriber might be obliged to refer to a list of dialling codes in order to obtain the necessary routing information. This is overcome by arranging for the national number dialled by the originating subscriber to be received by a 'register-translator' which examines the digits dialled and automatically furnishes the routing information. This examination of the dialled digits also determines charging rates.

In the major areas, London, Birmingham, Manchester, Liverpool, Glasgow and Edinburgh, the register translators needed to give s.t.d. facilities are being centralized by installing them in a particular exchange (Trunk Switching Centre) in each area, all other exchanges in the area having access to the switching centre.

The register-translator makes use of an A.T.E.-Sperry magnetic drum which is 9in in diameter, 34 of its 68 tracks containing permanent information. The recording and playback heads are separated from the nickel recording surface of the drum by a gap of not less than 0·001in. The drive motor is of the inverted squirrel-cage type, and is fed with a three-phase 50 c/s supply. The drum speed is 2160 rev/min and the drum speed-control circuit makes use of an eddy-current braking disk fitted to the rear of the motor shaft.

Electronic equipment

The drum rack, together with an associated relay-set rack, contains the necessary equipment for 48 registers, 47 of which are available for service. (One register is used for checking purposes.) The circuitry of the register-translator has been sub-divided into specific functions, for example 'dialling in', 'pulsing out', 'translation', etc. (Fig. 1) and each function is allotted its own unit or units. The circuit elements are manufactured in the form of wire-in sub-units, up to ten of which may be mounted on a unit. The clocks and scanners are also mounted in the form of units. The cold-cathode tubes associated with the outgoing scanner are in plug-in sub-units, of which there are two for each working register.

Clock circuits and scanners

Each connecting relay-set is linked through the incoming scanner and clock circuits with the portion of register track that forms its associated register. Each relay set has access to its individual register every time its associated portion of register track is passing under the 'read' and 'write' heads. Pre-read heads are fitted one register in advance of the normal heads to enable advance information to be obtained and a course of action set, before the register passes under the normal 'read' and 'write' heads.

The register track is a regenerative loop, so that each register makes what virtually amounts to two appearances on the register track, namely the point at which it is being read and the point at which it is being rewritten. Thus information that is being rewritten can be altered to add or subtract digits according to whether 'dialling in' or 'pulsing out' is taking place.

Each register track has storage space for nine registers, eight of which are used; the ninth space is left unused to allow the register track 'read' and 'pre-read' heads to be simultaneously switched to the common equipment. This space is also used for testing purposes.

Each register has storage space for 32 digits which are allocated as shown

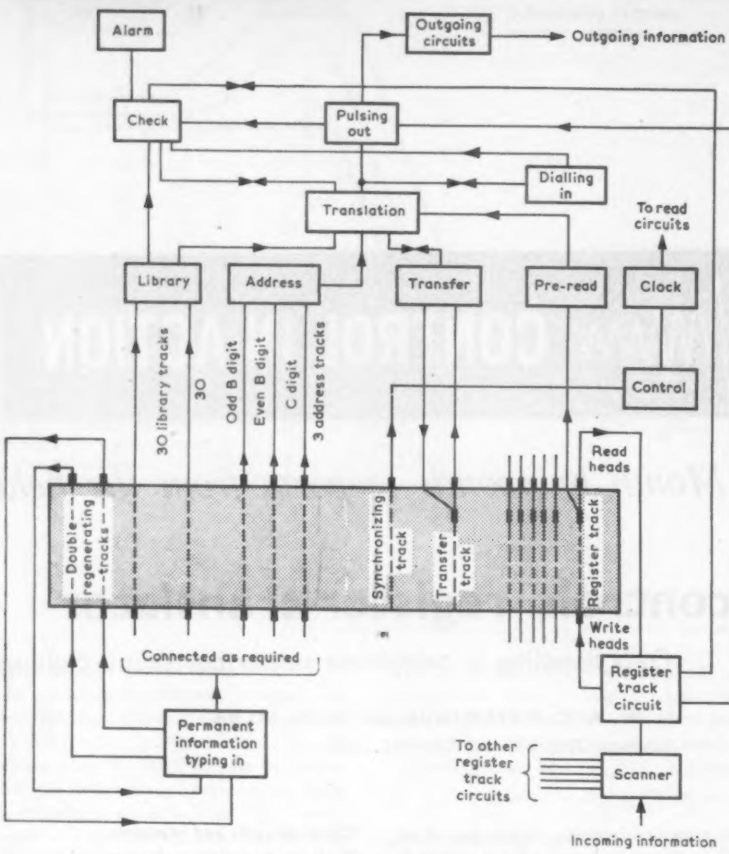


Fig. 1 Simplified schematic diagram showing paths between units

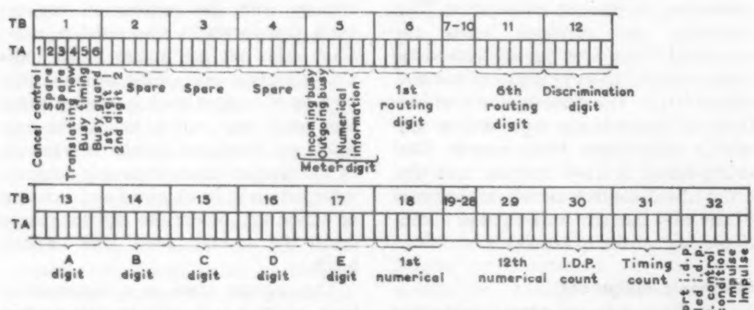


Fig. 2 Allocation of the 32 digits for a subscriber's register. TB6 to TB29 are similar to TB5. (Note: TB is a digit clock period; TA is a binary element clock period)

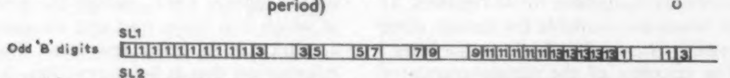


Fig. 3 Details of the address tracks. Non-standard digits 11 to 15 are used for checking purposes

in Fig. 2. A digit comprises six binary elements, and as each binary element occupies about 0·01in of track surface it can be seen that a register of 32 digits occupies approximately 2in of track.

In order that any part of a track may be accurately located, a system of clocks is built up and controlled by a synchronizing track on the drum. These clocks enable the scanner to link a connecting relay-set with its associated register on the track, and to locate any digit within a register, as well as performing other functions within the register-translator.

Translation

The system is designed to give a translation on three, four or five digits. The four- and five-digit codes are expanded from three-digit codes. Application is made for a translation as soon as the third digit is completely dialled. The translation received may be the final translation, or an intermediate translation indicating that the final translation is to be obtained from an expanded code. In the latter case, a further application for translation is made after the fourth digit has been completely dialled. Once again the received translation may be final or intermediate; if intermediate, a further application is made for a translation after the fifth digit has been completely received.

To obtain a translation, the first three digits dialled into the register, and henceforth referred to as A, B and C digits, are copied on to a track called the transfer track. The transfer track is a closed regenerative loop with an access time of eight digit clock periods. Anything written on to the transfer track is thus effectively repeated every eight digit clock periods around the entire periphery of the drum.

The principle used to obtain a translation causes the A digit to select a library track and the B and C digits to select one of the 100 translations available on the track. However, an individual track is of insufficient length to hold the full 100 translations, so that two tracks have to be used. The A digit, therefore, selects two tracks, one containing translations for B digits 1, 3, 5, 7 and 9 with their respective C digits, and the other translations for B digits 2, 4, 6, 8 and 0 with their respective C digits.

In order to locate correctly the wanted translation on a selected track, use is made of an address track, which ideally has all the 100 combinations of the B and C digits permanently written on it. However, owing to the track length being insufficient for the full 100 combinations, it is necessary to use three address tracks (Fig. 3), one for odd B digits, one for even B digits—the address track used being selected by the value of B digit circulating on the transfer track, and the third for storing all the C digits.

A comparison circuit compares the dialled B and C digits circulating on the transfer track, with the addresses as they are read from the address track. When coincidence occurs, the selected library track is connected and the next translation read is the one required. The translation is copied on to the transfer track, overwriting the A, B and C digits which are written upon it, and transferred into the originating register within 100ms.

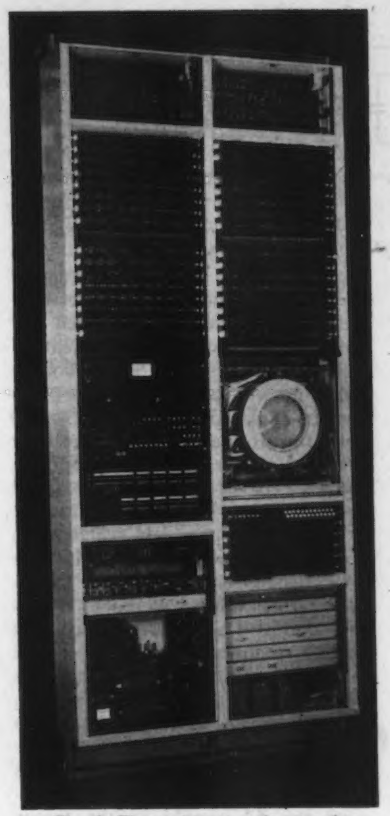


Fig. 4 The register-translator rack

If sufficient information is available as in the case of a three-digit code, then the translation received will be a 'final translation' and will contain a meter fee digit (charging rate for call), up to six routing digits, and a discrimination digit which indicates the 'pulsing out' sequences to be adopted.

If insufficient information is available to give a final translation, then an intermediate translation is stored in the library and subsequently transferred to the register. In the case of a four-digit code, the intermediate translation indicates that the code is one of ten associated with the particular three digits dialled and that the fourth digit must be examined. Should it be necessary to examine the first five digits, then the translation received as a result of examination of four digits will be a further intermediate translation.

Writing and permanent information

The so-called 'permanent' information covers such things as the synchronizing, address and library tracks. The synchronizing and address tracks are written on installation and never altered, but the library tracks which contain the translations are liable to be changed from time to time.

The selection of the library track and location of the wanted translation position is controlled by means of keys and switches located on the typing-in desk. Access to the write head of the library track to be altered is by means of a flexible cord connected to the double regenerative loop circuit.

Check circuit arrangements

The common electronic equipment of the register-translator is continuously monitored by means of built-in check circuits. Three separate checking facilities are provided covering the register track circuits, library track switching and the 100ms common equipment.

Circuit elements

The circuitry makes use of diode logic together with a large number of common 'bricks' these being 'read' and 'write' amplifiers, bi-stable trigger elements, pulse amplifiers, cathode followers, strobe generator and multivibrator.

Magnetic drum characteristics

A register is 32 digits long and each digit contains six binary elements or dots, so that there are 192 dots per register. With fifteen registers on a complete track, the total number of dots is 2880, and the digit-packing density is 101 dots/in. The access time of the register regenerative loop is the same as the repetitive sampling time of the incoming scanner, which is $16\frac{2}{3}$ms.

As the length of the regenerative loop is equal to nine registers, the rotation time is 27·75ms, and the drum speed 2160 rev/min. It follows that the operation frequency is 103·7 kc/s.

Progress

The equipment described has undergone extensive testing during development and has shown a high order of reliability. Equipment of this type is in public service in the London, Glasgow, Manchester, Birmingham, Liverpool and Edinburgh areas.

The authors thank the Automatic Telephone and Electric Co. Ltd for permission to publish this article.

Servo-control stabilizes magnetic field

D.C. supply to electromagnet stabilized to better than 1%

by **E. COHEN** *and* **D. S. GOSLING**

Research Department, Associated Electrical Industries (Manchester) Ltd

THE NEED HAS ARISEN IN THE AUTHORS' laboratory for stable magnetic fields of up to a maximum of 10 kilogauss in order to measure the electrical characteristics associated with low Hall constant semiconductors. This necessitated the design of a direct current supply to an electromagnet stabilized to better than 1%, with ripple content better than 0·5% and providing supply and load compensation. The magnet current is variable from 3A to 20A.

The system has to compensate for variation in the resistance of the electromagnet windings as temperature rises, and for variations in the supply voltage. Since both of these are relatively slow, a servo-mechanical system was used, a servo-motor driving the slider on a 7kVA Variac, *via* a 700:1 gear ratio, to increase or decrease the voltage across the electromagnet windings as necessary. The error voltage was obtained by passing a fraction of the magnet current through the heater of a temperature-limited diode form-

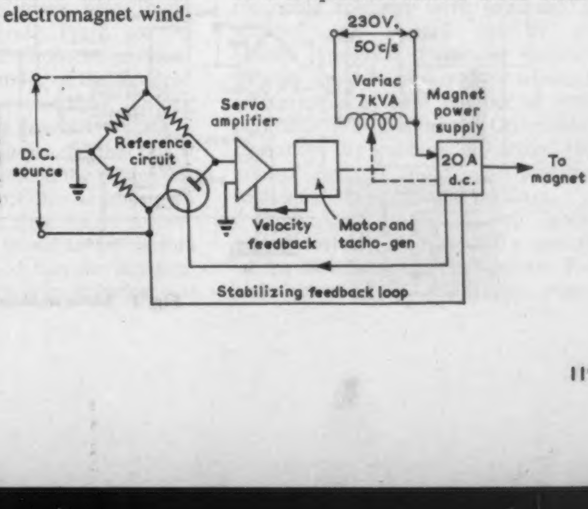


Fig. 1 A change in magnet current provides the error signal controlling a servo-motor driving a Variac's slider

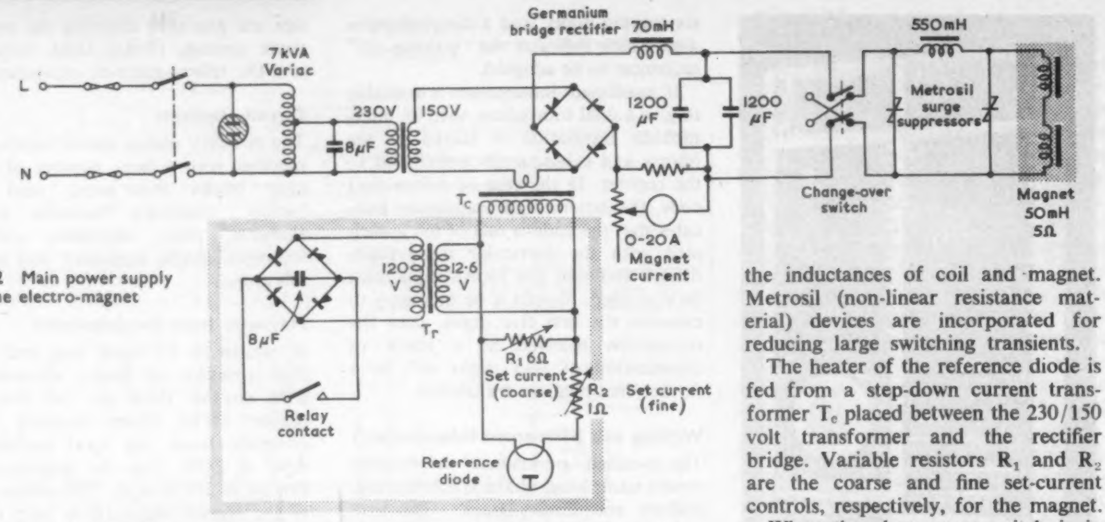


Fig. 2 Main power supply for the electro-magnet

ing one arm of a Wheatstone bridge. Any change in the magnet current, whether due to a change in power supply or a change in the winding resistance, causes an error voltage to be developed across the bridge. This is fed to a d.c. amplifier which then drives the split-field servo-motor in the required direction. (The design of the amplifier was based on a circuit evolved in the Automatic Control Section of the A.E.I. (Manchester) Research Department). As can be seen in the block diagram, Fig. 1, stabilization of the system is ensured by the use of velocity feedback from the servo-motor, which incorporates a tachogenerator, to the amplifier.

Electromagnet current supply

The electromagnet is made up of two main windings each consisting of six pancake layers of copper tape ¼in wide and 0·02in thick. The total number of turns is 2040, the resistance 5Ω and the inductance 53mH. When the maximum current of 20A is flowing, 2kW are being dissipated, causing the temperature of the windings to rise 50°C and the resistance to increase by 20%. Thus to maintain a steady current, an increase of 20% in the applied voltage is required over a period of approximately 30min, this being the time taken for the magnet to reach thermal equilibrium with its surroundings.

The 20A direct current required for the magnet is derived from the 230V a.c. mains supply *via* a 7kVA Variac, the slider of which is driven by the servo-motor. The output from the Variac is transformed to a lower voltage by a 230/150 volt transformer (see Fig. 2), rectified by a B.T-H. germanium bridge rectifier and passed to the magnet *via* an ammeter, a choke input filter and an iron-cored coil of 550mH inductance which is in series with the magnet windings. In this way ripple voltages from the filter output are further attenuated by the ratio of the inductances of coil and magnet. Metrosil (non-linear resistance material) devices are incorporated for reducing large switching transients.

The heater of the reference diode is fed from a step-down current transformer T_c placed between the 230/150 volt transformer and the rectifier bridge. Variable resistors R_1 and R_2 are the coarse and fine set-current controls, respectively, for the magnet.

When the changeover switch is in the neutral position, during the reversal of the magnet current for instance, the reference diode is de-energized and a large error signal is applied to the amplifier. This would cause the servo-motor to turn the slider of the Variac to its limit with possible damage to the apparatus. To eliminate this occurrence, transformer T_r, shunted across T_c and a bridge rectifier, energizes a relay which interrupts the 5A supply to the motor armature.

Servo amplifier

A circuit diagram of the servo amplifier and error detector is shown in Fig. 3. The bridge circuit is fed from a 1kV, metal rectifier, voltage-doubler circuit. The error voltage from the bridge is fed into one side of a double-triode, the other half of which amplifies the velocity feedback voltage from the tachogenerator. The two halves of the double-triode are cathode-coupled, and the d.c. output from them is fed to the two push-pull output valves which drive the two halves of the split-field winding of the servo-motor. The current in the two motor windings is continuously monitored and, when no error signal is present, the whole amplifier is balanced to give equal currents in these two windings by means of a balance control in the anode circuit of the double-triode.

Conventional power supplies are used in the amplifier. The motor power supply shown diagrammatically in Fig. 4, provides 24V to feed the servo-armature and the tachogenerator field.

Setting up the equipment

After allowing a period of 10min for warming up, and with the feedback

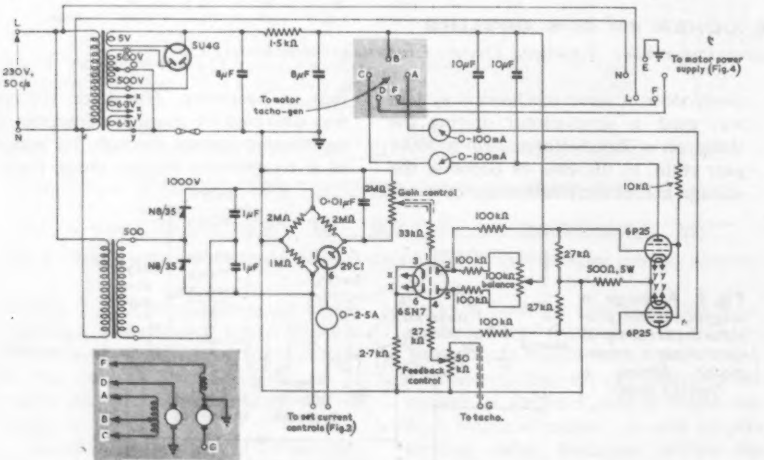


Fig. 3 Servo amplifier and error detector.

and gain controls set at zero, the $100k\Omega$ balance potentiometer is adjusted to ensure equal anode currents in the 6P25 output valves as indicated on the front panel meters (see photograph, Fig. 5). The gain control is then set to the minimum and the feedback control advanced until oscillations stop. Then the gain is increased while at the same time the feedback potentiometer is adjusted for complete stability.

To obtain a known current through the magnet windings, the coarse and fine set-current controls are adjusted until the main magnet current attains the required value as indicated by the magnet current meter.

Performance

Using the stabilized supply, the magnet current is invariant when the mains voltage changes from 200V to 260V centred on a nominal supply of 240V. So far as load variations are concerned: using a variable dummy load, initially adjusted to 5Ω (i.e. simulating

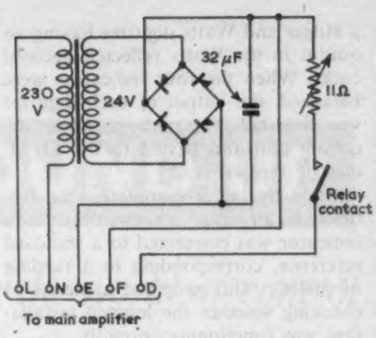


Fig. 4 The servo-motor's 24V power supply.

the resistance of the magnet coils) and varying this by $\pm40\%$ leads to a variation of current not exceeding 0·5%. The choke input filter and series inductance ensure that the ripple current is less than 0·5% at maximum rating.

Acknowledgement

The authors wish to thank Sir Willis Jackson, F.R.S., Director of Research, Associated Electrical Industries (Manchester) Limited for permission to publish this article.

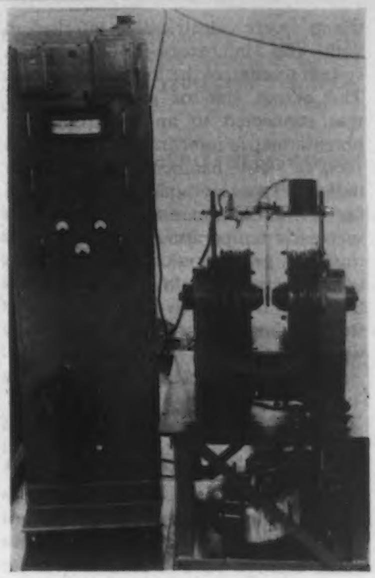


Fig. 5 The stabilizer and the electro-magnet

Stress relief under control

Watching 400 temperatures at Hunterston

SUCCESSFUL STRESS-RELIEF OF THE first 70ft-diameter pressure vessel at Hunterston nuclear generating station is reported by G.E.C. The pressure vessel and included components were heated by a series of freely radiating Brightray strips supported by wire links and ceramic insulators. Some strips were mounted circumferentially between the spherical pressure vessel and the cylindrical inner heat shield while others on the top and bottom crowns followed approximately the curvature of the vessel. A curtain-like structure of heater elements was built up in the space between the inner heat shield and the pressure vessel.

Temperatures were measured at some 400 points by means of chromel-alumel thermocouples. The readings from these thermocouples were recorded by two different instrumentation systems.

In order to eliminate the fatigue and consequent inaccuracy arising from the continuous logging of large numbers of temperatures by an operator, two special instrumentation and recording systems were employed. About three-quarters of the thermocouples were connected to a digital typewriter recording system which presented the temperatures in a printed list, while the remaining quarter were connected to six strip-chart recorders. This procedure was adopted for two reasons. First, the strip-chart recorders could be used to control the heating cycle for a limited period in the event of failure of the digital typewriter system (or *vice versa*), and secondly the strip-chart instruments provided a record which could be interpreted more quickly and easily than that of the digital typewriter.

As readings of the temperatures were taken from the recorders they were plotted on a specially constructed peg board in the control room. Temperature was plotted horizontally (in 5degC steps) and the hundred thermocouples were plotted vertically.

Adjacent to this board were two models, one of the pressure vessel and the other of the inner heat shield resting on the grid. Fixed to the models were small lamps in positions corresponding to those of the hundred thermocouples represented on the peg board. By placing a small plug in a thermocouple position on the board the appropriate lamp on the model was lit. The purpose of this arrangement was to enable the position of a thermocouple in the vessel to be located quickly if it showed that the temperature in that part was differing too widely from the mean temperature of the whole structure. Remedial action could then be taken by reference to electrical control information on the peg board.

Forming part of the peg board were two other display systems. The first showed the power loading of each heater circuit in the pressure vessel and the tapping position of each of the 24 auto-transformers; and the second showed the cycling of the tubular duct heaters. The complete peg board and models were designed and constructed by the S.S.E.B. Industrial Advisory Service.

The equipment for the digital display system was specially developed by G.E.C. and was arranged for either automatic or manual operation. When operation was automatic all the thermocouple readings were sequentially scanned and printed out by an electric typewriter. Particular thermocouples could be observed by selecting and printing a fewer number of temperatures more frequently. On manual operation, by pushing a button, the control engineer could select and log individual thermocouple readings.

Four uniselectors, having gold-plated contacts, each handled a quarter of the 300 thermocouple circuits. The uniselectors were driven by relays

which were electrically interlocked with the indicators and print-out system to control the logging sequence. The output side of each uniselector was connected to an Electroflo 198 potentiometric indicator scaled to read 1000°C. The balancing time of the indicator was nominally one second, but if the difference between the two successive temperatures was small, this time was greatly reduced. In order to take advantage of this, balancing detectors were fitted so that printing-out started immediately all four indicators were balanced.

Each indicator was also fitted with a Hilger and Watts digitizer having an output in the Watts reflected decimal code. When the four indicators were balanced, the output of each digitizer was decoded in turn by a single decoding unit and passed to the I.B.M. electric typewriter.

Once during a complete scan (*i.e.* through all four uniselectors), each indicator was connected to a standard reference, corresponding to a reading of 800°C. This provided a means of checking whether the logging installation was functioning correctly.

Accuracy of the potentiometric indicators was 0·25% f.s.d. and the accuracy of translation was ± 1 digit. The system was calibrated at 550°C and a correction card was made to cover other temperatures.

Since the electric typewriter was able to print ten digits a second, multi-bank uniselectors capable of switching the inputs of the four indicators simultaneously were employed, the four outputs being printed out sequentially. The printing rate was thus $2\frac{1}{2}$ digits a second. Additionally the five differential themocouple readings were registered on a separate chart recorder so that special and continuous observation was possible.

Turbine as a power servo

To be demonstrated for the first time in this country, at the S.B.A.C. Show (see preview on p. 105), is the automatic control of a Westland Wessex helicopter. All-weather day-and-night anti-submarine action is made possible by the automatic control, and the helicopter carries detectors and armament. In the form in which it is entering service in the R.N., the Wessex is powered by a Napier Gazelle free-

Auto-controlled Wessex 2

turbine engine. The Wessex 2 pictured above is a more powerful development fitted with two 1250shp de Havilland Gnomes, also free-turbine engines. Automatic controls simplify the pilot's task, but much skill goes into the necessary integration of power plant and rotor. An account of the helicopter turbine as a power servo was given by R. A. Morley in *Control*, September and October 1959.

Auto-production at Swindon

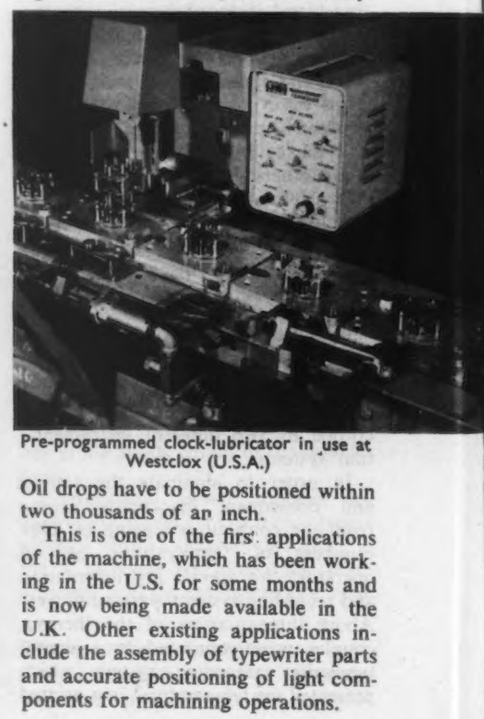
Semiconductors Ltd, the Plessey-subsidiary at Swindon manufacturing transistors, are now operating a second automatic transfer line on a full three-shift basis. Their original automatic line was installed three years ago, and now both lines are producing high-speed switching transistor 24 hours a day, five days a week. Little positive information has been released on either the method of operation or output of these automatic transfer lines. The original line carried out some seven operations automatically, including etching and cleaning of the germanium blanks. The second line is known to incorporate the various modifications which Semiconductors' operating experience over the past three years has led them to develop.

Plessey, incidentally, have just purchased the minority interest in Semiconductors held by the Philco Corporation (U.S.A.), thus making the Swindon firm a wholly-owned member of the Plessey group. Semiconductors Ltd remain a non-exclusive licensee of Philco for the manufacture and sale of transistors.

New automatic transfer line at Semiconductors, Swindon

Robot lubrication and assembly

The U.S. Industries 'Transferobot' assembly and transfer machine is being used by the Westclox Division of General Time Corp., La Salle, Illinois, to oil clock bearings automatically. The Transferobot is designed for a wide variety of assembly-line manipulations, the mode of operation being determined by an electronic programming unit and interchangeable head accessories. In the Westclox oiling application, the completed clock assemblies pass the machine at the rate of one a second, and eight bearings are lubricated simultaneously.



Pre-programmed clock-lubricator in use at Westclox (U.S.A.)

Oil drops have to be positioned within two thousands of an inch.

This is one of the first applications of the machine, which has been working in the U.S. for some months and is now being made available in the U.K. Other existing applications include the assembly of typewriter parts and accurate positioning of light components for machining operations.

NEWS ROUND-UP

from the world of control

DATA PROCESSING

Atlas for research

A Ferranti Atlas, claimed to be the world's most powerful digital computer, has been ordered for the National Institute for Research in Nuclear Science.

Ferranti's tell *Control* that in Atlas they have got the utmost out of standard, proved, readily available electronic components. Greater speed, they say, could only have been obtained by using entirely new electronic circuits. The Atlas will perform about a million simple operations (e.g. additions), or about 300,000 more complex operations (like multiplication) a second. The machine will take a 48-bit word and this can be used for fixed-point numbers (forty digits long), floating-point numbers (eight digits for the exponent), alpha-numerical data (eight six-bit characters) or for propram instructions (ten digits for the function part, the rest for various addresses). The various input and output equipment includes magnetic-tape stores capable of transferring 90,000 characters/s. Time-sharing will allow transfers of information between the computer and up to twenty peripheral units and eight magnetic-tape units simultaneously. The high-speed magnetic-core main store is backed by four magnetic drums which have slower access but much larger capacity. This is a familiar way of avoiding the cost of a high-speed core store of sufficient capacity, involving continual transfer of large blocks of information from drum store to core and back. In most computers these transfers have to be performed by instructions written in the program, which often does not give the most effective utilization of storage capacity. In Atlas the whole job of storage 'housekeeping' is taken over by an automatic system, and the programmer works as if there were just one high-speed single-level store of large capacity. The 'page address' system is used for the stored numbers and instructions (numbers do not have positional addresses but are identified by their presence in particular blocks of numbers ('pages') at particular points in those blocks, the pages having no fixed places in the stores).

The automatic system for allocating storage space is actually operated by special electronic circuitry under the control of a short, fixed sequence of instructions. This short routine is held permanently in a special store, said to be of unique design, along with other fixed routines (about 250 altogether) frequently used for arithmetic and internal control operations—in fact all the operations normally found in the sub-routine library of any well-equipped computer.

Routines are put into this fixed store initially by inserting small rods of magnetic material into a wire-mesh sensing system, which links with the rods magnetically and produces digit pulse patterns corresponding to the spatial patterns of the rods. (Strictly, this store is a semi-permanent one, because the routines can be changed manually.) To call one of the fixed routines into action, the programmer writes a single instruction into the main program. The computer automatically distinguishes these 'extracode' instructions from the normal instructions and switches control over to the fixed store whenever they occur in the program. Reading out from the fixed store is extremely rapid (access 0·3μs), and many of the complete routines are performed in times not much greater than for some of the normal program instructions.

Another design feature is a new type of adding circuit with a 'carry' operation that is always completed within the transfer time of Atlas, which is a fraction of a millionth of a second.

Multilingual glossary

Two international organizations are collaborating to develop a multilingual glossary of automatic data processing terminology. They are the International Federation of Information Processing Societies and the Provisional International Computation Centre, who have agreed to make the completed glossary available to the International Organization for Standardization.

The automated messenger

The possibilities of dispersed organizations, such as chain stores and banks, making direct use of centralized computer services by communication over P.O. lines, were demonstrated recently by S.T.C. In the demonstration, data were transmitted from London to a 'Stantec' computer in Harlow, and the required results sent back to London.

S.T.C. intend to market a range of equipment for this type of application, having in mind the demand for such services as centralized accounting, stock control and invoicing, without the delays associated with the physical carriage of data. The speed of such systems would depend on the amount of data to be transmitted. Low-speed links would normally use telegraph circuits, but for higher speeds of transmission the wider frequency band available on telephone circuits would be required.

In the demonstration, transmission was at 1000 data bits/s on the incoming lines to the computer, and at 50 bits/s on the return lines.

CLERKING

B.E.A.'s booking system

B.E.A. has entered a £2,500,000 contract with Standard Telephones and Cables Ltd for a new push-button reservation system. The contract is for the first part of an electronic, automatic seat-booking system which—at an estimated ultimate cost of £4,500,000—will be the biggest of its kind in Europe and one of the most modern and most fully-automated systems employed by any airline.

Four electronic computers will form the heart of the system and will be installed in B.E.A.'s new permanent west London air terminal, now under construction. Reliability will be ensured by the interconnexion of all four computing machines so that all booking status records can be fully duplicated. The automatic reservation system will give B.E.A. close control of bookings of all services up to a few hours before departure time, making it possible to resell late cancellations and accept late bookings with minimum risk of turning would-be travellers away when seats are still available.

Operating details

The central computing and storage equipment will consist of two pairs of large program-controlled computers.

One pair will process reservations on domestic services and the other pair will handle international services. Both pairs will perform similar functions and be interconnected to allow cross-reference and to duplicate records against equipment failure. One computer in each pair will handle all information relating to seat availability and seat-booking inventories. Most of the information processed here will be digital, and this machine is therefore designated the 'numerical' computer. The other machine in each pair will handle information on the names, addresses and detailed requirements of passengers who have made bookings. This is primarily an alphabetic function and the machine is designated the 'nominal computer'.

The backing store used with each numerical computer will comprise up to twenty high-speed magnetic drums, each capable of storing records for about 2000 flights covering an eleven-week period. Seat-availability information on any individual flight may be obtained by sales clerks in a few milliseconds.

Each nominal computer will have a backing up to 200 special rapid-access magnetic-tape mechanisms, storing the records for up to a million passengers. Any record will be retrievable for examination or amendment in about five seconds.

Each reservation office connected into the system will have a number of desks each containing a push-button unit for seat-availability interrogation and seat booking, and a special teleprinter for transmitting passenger details to the nominal computer. The reservation clerk will use the push-button set to check seat-availability, on receipt of an enquiry from an intending passenger. The clerk will select one of a number of metal plates on which are printed details of several related flights, insert the plate into the push-button set, and then press the buttons corresponding to the date of the flight, the departure and arrival point, the class and number of seats required. Upon pressing the 'ask' button, a composite, digital message, made up of the key settings and a code which identifies the particular flight plate, will be sent over a leased landline to the numerical computer. A message indicating the availability of seats on all applicable flights on the flight plate will be sent back to the push-button set and displayed by means of an array of coloured lamps above each column on the plate. The customer will be offered the alternative shown, and the chosen flight will be identified by pressing the appropriate selector button. The 'book' button will be pressed and the new message (date, class, number of seats, flight sector and flight number) will be sent to the numerical computer. The booking having now been made, the numerical computer will inform the nominal computer, which will send a confirmatory message to be printed out on the sales clerk's teleprinter. The clerk will complete the transaction by typing the passenger's name, contact address etc., this information being recorded in the magnetic-tape store associated with the nominal computer. The nominal computer will check that this information has been stored correctly and advise the clerk that this is so. If the passenger later wishes to cancel his booking the reservation clerk can, by inserting the key details on his teleprinter, cause the nominal computer to search for the required record. When the record has been found and reproduced on his teleprinter, the clerk can then introduce a cancellation routine which will automatically put the cancelled seat or seats back into the inventory held in the numerical computer, for resale.

I.D.P. for N.C.B.

A.E.I. have received an order worth more than £250,000 from the Scottish Division of the National Coal Board for a fully integrated data processing system incorporating the A.E.I. 1010 digital computer. This will be one of the installations which will play a part in the eventual unification of data processing throughout the whole coal industry in this country. The company states that A.E.I. 1010 is the fastest computer of its kind available. It will handle wage and salary data of 90,000 people in 132 colleries, 22 brickworks and other establishments. It will also do materials and supplies accounting, involving costing and processing of 14,600 stores items a day, and will record despatch of 4,500 loads of coal a day. Since there are some 1200 different qualities of coal, the latter is a complicated task.

ASSEMBLY

For short light runs

Claimed to represent a new approach to automatic production machinery, the 'Transferobot' was demonstrated in London recently by U.S. Industries, Inc. (Great Britain). Basically, this is a small machine designed to replace the human operator for repetitive light assembly and transfer operations. It differs from most other machines in this field in that it is capable of a large number of movements (picking-up, rotation, insertion, transfer and so on) and can be programmed to carry out many different operations. It is thus expected to be an economic proposition for small firms engaged on relatively short production runs. The time required for re-programming is said to be of the order of an hour. A warning system is incorporated in the machine, which operates if any fault occurs in the operating cycle. The nominal weight-capacity is a pound. Existing applications in the U.S. include the manufacture of clocks, business machines, razors and electrical equipment (see *Control in action* this month).

SPACE

Europe launching out

The announcement that the Federal German government is willing in principle to participate in a European organization for the development of space-vehicle launchers, as proposed by the British and French governments, has drawn attention on the British Blue Streak first-stage launcher.

The course for control

The Anglo-French proposals for a European launcher, which were issued at Strasbourg last February, envisaged the use of Blue Streak with a French-made second stage and an unspecified third stage. With Blue Streak as the first stage of a hundred-ton three-stage rocket, the vehicle would rise vertically for twenty seconds, climbing steadily to about 2000ft. It would then begin to turn over slowly until the desired trajectory angle (about 30° to the horizontal) was reached. The vehicle's speed at this stage would be 2500 mile/h and its height nearly eighteen miles. It would then accelerate up a straight climb path until its speed reached 8500 mile/h and all its propellants were burnt. The time from launch to first-stage burn out would be about 106s, the altitude fifty miles, and the position eighty miles down range. When the engine cut off the ignition process for the second-stage rocket would be started and it would then draw clear. The spent Blue Streak would fall away in a ballistic trajectory. The French second stage would increase the speed from 8500 mile/h to 14,500 mile/h along a straight line in space. This speed would be reached with the rocket some 250 miles down range and 105 miles high. At this point the second stage would hand over to the third stage and begin a long fall back to earth. Finally the satellite would have to be at orbiting speed and height,

moving horizontally for a circular orbit or climbing at the appropriate angle for an elliptic orbit. The final speed would be between 17,000 mile/h and 24,000 mile/h.

Blue Streak's propulsion

The propulsion system for Blue Streak comprises two Rolls-Royce RZ.2 rocket engines. The engines in this installation are quite separate units, each with its own propellant feed, combustion and control system. An electro-pneumatic sequential system is used for operating the various valves during starting up and shutting down. This is a ladder-type system, in which no given operation can take place until a signal has been received signifying that the preceding operation has been satisfactorily completed. Propellants for starting the engine are supplied from pressurized ground-mounted tanks, and ignition in the gas generator and thrust chamber is by pyrotechnic igniters.

Seventeen manned orbits

On 6–7 August, Major Gherman Titov completed seventeen orbits of the earth in the 4½ton Soviet space vehicle *Vostok II*. Much hard technical information beyond this statement is impossible to obtain. *Control* understands that there was a good deal of programmed control involved, and that manual override arrangements enabled Major Titov to influence the course of events.

PROFESSIONAL

Summing up cybernetics

The Institution of Production Engineers enjoyed its eleventh annual summer school at the College of Aeronautics, Cranfield, on 29 August–1 September, discussing *The Interrelation of Work Study, Ergonomics, Operational Research and Cybernetics*.

Dr E. Edwards, of Loughborough College of Technology, was the speaker most devoted to cybernetics. In classical physics, he said, energy is the most basic concept, and its study in various forms makes up the greatest part of the subject. The development of more complex machines, together with the colossal rise in communications techniques and also the appearance of a genuinely scientific study of animal and human behaviour, have given rise to a large new section of physics and engineering. Here the emphasis is no longer upon energy, but upon information and control. Dr Edwards went on to define 'cybernetics' as the science of control and communication. This definition, he explained, is intentionally broad in its scope. Cybernetics is not confined to electronic control systems, nor to hydraulic ones, nor to physiological ones; neither is it concerned only with servo-mechanims or large-scale data-processing systems. Yet, to some extent, all these things are of interest to the cybernetician, whose concern is with the general properties of information flow, whether or not the system under consideration exists, or even could exist, in this world. Perhaps this suggests that cybernetics is unique in its extreme of uselessness, remarked Dr Edwards, and went on to deny that such is the case.

BUSINESS

Elliott's analysis

Elliott Brothers (London) Ltd have started an Automation Analysis Department. The company has obtained experience of both on-line and off-line computer applications through its service centres and its American connexions. It has found that in the great majority of cases there is no precise knowledge of the mathematics of industrial processes. In America, the U.S.S.R. and certain eastern European countries, the industrialists are installing computers (e.g. the Elliott 803) to gather and evaluate data. The intention in these cases is to find the true natures of the processes involved and then to put the computers on to operational control. In Britain (say Elliott's) there are no immediate incentives to do this sort of thing, and the result is that automation is being delayed. The new Automation Analysis Department, under the leadership of Dr. L. C. Payne, is to devote itself particularly to this problem.

Automation with muscules

Hawker Siddeley Engineering, a new division of Hawker Siddeley Industries, has been formed to design and construct comprehensive systems such as harbour installations, radio telescopes, sewage plant, automatic railway controls, automatic warehouses, automated manufacturing plant and telemetry applications. Commenting on the formation of the new division, Sir Roy Dobson, Vice-Chairman and Managing Director of the Hawker Siddeley Group, said: 'We have launched an entirely new concept—automation with muscles. By integrating the latest aviation techniques with our traditional heavy engineering skills, we can offer a new kind of industrial packaged deal, centrally planned and controlled by a single contractor. We are confident that the new division will create opportunities for further expansion in the export market.'

NEWS BRIEFS

Control for harbour cranes The complete electrical equipment of eight harbour cranes for the Amsterdam Harbour Board is to be supplied by Metal Industries (Europe) S.A. The contract, which is valued at nearly £50,000, calls for the supply of automatic control panels, motors and installation. The control panels will be manufactured by Brookhirst Igranic at Bedford and the motors by Lancashire Dynamic & Crypto at Trafford Park.

Rheostatic Company and Robertshaw Controls S.A., Geneva (a subsidiary of Robertshaw-Fulton Controls Co., U.S.A.) have entered into agreements in order to complement their respective ranges.

Design appreciation Two-phase staff course, bridging 'design' and engineering, is to be held in the London area by the Council of Industrial Design, 23–27 October and 20–24 November. Executives will be served on 27 November–1 December. Forms from Miss Sydney Foott, Education Officer, Co.I.D., 28 Haymarket, London, S.W.1.

Mullard move The commercial divisions and most of the production staff of Mullard Equipment Ltd will move to their new factory on 4 September, 1961. Products will include industrial control systems and sub-assemblies, nucleonic instruments and equipment, and electronic measuring and test apparatus. The address and telephone number of the new plant is Manor Royal, Crawley, Sussex. Telephone Crawley 26386.

Transatlantic link Electro Mechanisms Ltd, one of the King group of companies, is linking with Schaevitz Engineering of New Jersey, U.S.A. The Electro Mechanisms range of transducers and amplifiers will now include the Schaevitz range of linear and rotary differential transformers, dynamometers, transducers and centrifuges. The agreement between the companies provides for exchange of technical information. The address of the company remains 220 Bedford Avenue, Slough, Bucks.

Automatic exchanges for Navy A.E.I. has a £57,000 order from the Admiralty to supply and install two 'satellite' telephone exchanges in the Portsmouth Dockyard Area. A 400-line private automatic branch exchange is to be provided for Eastney Royal Marine Barracks, and a 600-line exchange of the same type for establishments near Gosport.

Hydraulic control The Hydraulic Plant and Machinery Group of the I.Mech.E. is to hold a conference on 'Oil Hydraulic Power Transmission and Control' on Wednesday 29 November and Thursday 30 November, 1961. Registration forms on application to Secretary, 1 Birdcage Walk, Westminster, London, S.W.1.

FROST MILWARD
reserving flights

PEOPLE IN CONTROL

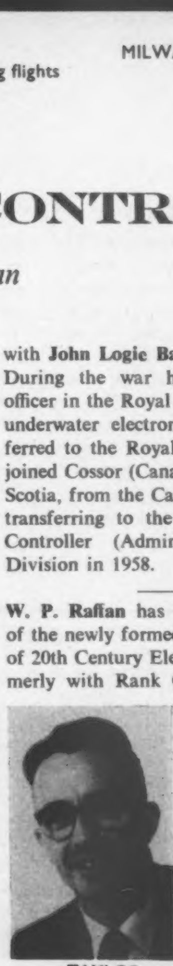
by Staffman

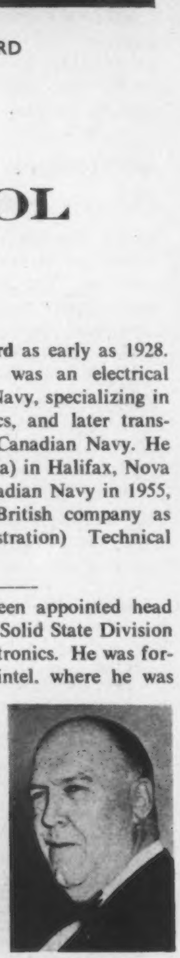
R. J. Redding is leaving Evershed and Vignoles after ten years of creative work on electronic process control equipment and on-line computery. From his post as Chief Technical Engineer at Evershed's, Redding goes to the Technical Group of Constructors John Brown as Senior Engineer for instrumentation and control. He hopes to get closer to the practical problems of users in his new job, and may well find excellent application for his special knowledge of equipmental safety in explosive atmospheres. As many readers will know, Redding is a member of the S.I.T. Council and Vice-chairman of its Control Section.

'Like all family businesses we have reached the stage where we require more capital' remarked **Richard Walker**, Managing Director of Walker Crosweller & Co., when discussing his company's recent decision to offer shares to the public. Walker Crosweller was formed in London forty years ago by the present Chairman, **J. M. Walker** (Richard's father) and the late **W. W. Crosweller**, and specializes in water-temperature control (thermostatic mixing valves), and industrial instruments concerned with draught, vacuum, pressure, rate-of-flow etc. I gather that the European Common Market, and the export credit problem (120 days is not uncommon) have a great deal to do with the company's decision.

J. D. Percy, who has been appointed Technical Sales Manager of Cossor Radar and Electronics, has had an interesting career. He was a pioneer in television design as a young man, being associated with **John Logie Baird** as early as 1928. During the war he was an electrical officer in the Royal Navy, specializing in underwater electronics, and later transferred to the Royal Canadian Navy. He joined Cossor (Canada) in Halifax, Nova Scotia, from the Canadian Navy in 1955, transferring to the British company as Controller (Administration) Technical Division in 1958.

W. P. Raffan has been appointed head of the newly formed Solid State Division of 20th Century Electronics. He was formerly with Rank Cintel, where he was concerned with the development of precision monoscopes, skiatrons, and photoelectric devices. During the past three years he has been developing special solid-state devices.





TAYLOR CLARK
recording flights

The drift continues from aviation electronics into more general industry. Now I learn that **G. D. Taylor**, formerly Head of the Flight Research Department at Bristol Aircraft, has joined Epsylon Industries as Chief Applications Engineer. Taylor joined Bristol Aircraft from Leeds University in 1949 as a Flight Research Engineer. His experience should be particularly valuable in the application of magnetic tape recording equipment for instrumentation.

Elsewhere in this issue there is a report of the new push-button reservation system that B.E.A. plans to be operating in about two years' time. The first part of the contract has gone to S.T.C. for £2½m, and my heading picture shows B.E.A.'s Chief Executive, **Anthony H. Milward**, signing on the dotted line. **K. A. F. Frost**, signing for S.T.C., is the one with the smile.

English Electric's Control Gear Division at Kidsgrove has acquired **Bernard Feltbower** as Chief Engineer. He was born in Vienna nearly fifty years ago and holds both Viennese and British qualifications. Feltbower will be responsible for all the technical administration and new projects at Kidsgrove, which specializes in electric motor control and the engineering of automatic control schemes for industrial processes. Feltbower joined Brookhirst Switchgear in 1938, where he was responsible for the design and application of control gear. From 1947 until this year he worked for Electro Dynamic Construction, where he became General Manager and Chief Engineer for their Control Gear Division. During this time he was responsible for developing, among other things, automatic standby power supplies for conventional and nuclear power stations etc. Feltbower has contributed variously to the literature of automatic control and has outside interests that include archaeology and music.

Mergers go on following each other. I was not unduly astonished to hear that that much-ramified concern the Plessey Co. is acquiring A.T.E. and Ericsson's (*inter alia*). At Farnborough time (see p. 105) it is interesting to recall that American-born **Sir Allen Clark**, Plessey's Chairman and Managing Director, is an ex-R.F.C. man who is still interested in

FELTBOWER RAFFAN
solid development

aeroplanes—he is on the council of both the S.B.A.C. and the Telecommunication Engineering and Manufacturing Association.

Shifting to a new kind of preoccupation with the dynamics of fluids is **R. Hadekel**, whose copious contribution to the literature of hydraulic servo-mechanisms will be familiar to many readers of *Control*. For some years a consultant to Sperry, he has now become Chief Engineer at Trico-Folberth, the screen-wiper and washer makers.

That well known globe-trotter **Laurie Woodhead** of Cossor has taken on yet another public-spirited commitment, chairmanship of the I.E.A.-show organizing committee. I am told that Woodhead was the first radio-valve salesman in this country—in 1919—and that he'd been round the world twice before he came of age. A keen instrument man, he can still surprise people with his imaginative predictions. The I.E.A. show should be the better for that.

Bisra's Director, **Sir Charles Goodeve**, is a distinguished patron of o.r. work, and is of course particularly well placed to appreciate its value. Now he is calling for suggestions in connexion with the third conference of the International Federation of Operational Research Societies (see *Looking ahead*, p. 4). Sir Charles is Secretary of the Federation, and would welcome proposals sent to him at 11 Park Lane, London, W.1.

I hear that Tecalemit (Engineering) Limited has been formed as a new company to do all the manufacturing, engineering and selling previously done by Tecalemit Limited. The board is chaired by **S. G. Gates**. **P. R. Scutt**, **T. R. Hardman**, **J. E. Drinkwater** and **H. E. Jackson** will look after Managing, Sales Production and Engineering respectively.

AUTHORS IN CONTROL

J. C. Smith (with I. C. Ross, *Control of a modern cold rolling mill*, page 88) is a member of the Electrical Engineering Department at Steel Peech and Tozer. Educated at Rotherham Grammar School and Rugby College of Engineering Technology, he served an engineering apprenticeship at A.E.I. (Rugby) Ltd. A Graduate member of both the I.Mech.E. and the I.E.E., and holding a postgraduate diploma in applied mechanics from the University of Sheffield, Smith has been engaged on the design, installation and commissioning of electrical plants since 1955.


SMITH


ROSS

I. C. Ross (with J. C. Smith, *see above*) has been manager of the Instrument Department at Steel Peech and Tozer since March 1959. Educated at Rotherham Grammar School and Rotherham Technical College, he served an engineering apprenticeship at Steel Peech and Tozer. Ross spent his National Service as a Workshop Officer in R.E.M.E., and is a member of the Society of Instrument Technology.

A. T. MacDonald (*Torque- and velocity-limited servo mechanisms*, page 93) received his technical education at Glasgow Royal Technical College and Birmingham University. He served an apprenticeship with Sir William Arrol and Co. Ltd, and in 1945 joined the Royal Naval Scientific Service with which he worked on control systems for underwater weapons. In 1956 he joined the Industrial Applications Division of E.M.I. where he worked on machine tool controls and allied systems. MacDonald joined Sperry Gyroscope in 1959, and is now Engineering Superintendent, Industrial Systems at Sperry's Brentford Division.

H. Graham Flegg (*Summer-school mathematics for control engineers*, page 97). See page 113, August 1961.

P. F. Blackman (*Pole-zero approach to system analysis*, page 101). See page 126, November 1960.

W. A. C. Hemmings (with W. H. Files, *Magnetic drum controls register-translator*, page 117) is an executive engineer with the Automatic Telephone and Electric Co. Ltd, Liverpool. Born in 1926, he entered the P.O. Engineering Department in 1941 and was engaged in automatic telephone exchange maintenance, exchange construction, and special fault investigation. He joined A.T.E. in 1954 and worked on the circuit design for 2 V.F. signalling and Crossbar telephone exchange systems. In 1957 Hemmings transferred to the Research and Development Division and was appointed company liaison officer to the P.O. Engineering Department for the development and production of the magnetic drum controlling register-translator.

W. H. Files (with W. A. C. Hemmings, *see above*) is a senior project engineer with A.T.E., Liverpool. He served an electrical engineering apprenticeship before joining the Research and Development Division in 1957, and has been a member of the team responsible for development and production of the magnetic drum register-translator. Files studied at Liverpool College of Technology, becoming a Graduate member of the I.E.E. in 1959.

Emanuel Cohen (with D. S. Gosling, *Servo-control stabilizes magnetic field*, page 119) was born on 23 January 1924. Educated at Highbury County School and Kings College, London, he took his B.Sc. in special physics in 1948 and his M.Sc. in 1950. A sergeant radar mechanic in the R.A.F. 1943–46, he was subsequently a development engineer with Ultra, an X-ray crystallographer with Pilkington Bros., and a physicist at the British Rayon Research Association. He is now an applications engineer in the


COHEN


GOSLING

Semiconductors Dept. at A.E.I. Manchester, and is devoting himself to the use of the Hall effect in control, analogue computation and telecommunication.

David Samuel Gosling (with E. Cohen, *see above*) was born 18 February 1937 and educated at Stockport School and Nottingham University. He took his B.Sc.(Hons) in physics in 1959 and was apprenticed to A.E.I. in Manchester. He is now in A.E.I.'s Semiconductor Department studying epitaxial growth with germanium, and high-electric-field effects in germanium and silicon.

New for the user

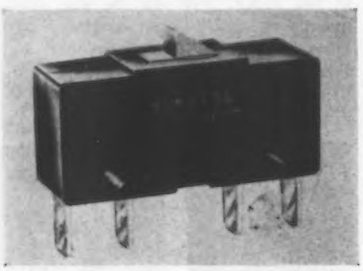
A monthly review of instruments, components, equipment and machinery for automation

For further information, circle the appropriate number on the reply card facing page 162

SMALL SWITCHES

high current ratings

The K5 series of switches, made by Burgess, may have plunger or cam-follower actuator, and are all about matchbox size. They are rated at 25A, 250V a.c. for resistive loads, and other ratings include 15A, 440V a.c. and 0·5A, 250V d.c. (resistive load) and 15A, 250V a.c. (inductive load). Switching facilities include change-over, normally-open only



Plunger- or cam-actuated

and normally-closed only, in both plunger and cam-follow models. The illustration shows the K5C, a cam-follower, changeover, switch.

Circle **No 549** on reply card

CALIBRATED DISPLAY SYSTEM

multi-channel

Model 5934, made by Philbrick (U.S.A.) for use with analogue computers, simulation systems etc., will display simultaneously on a 17in cathode ray tube up to eight input signals superimposed on an electronically generated co-ordinate system. The simultaneous display of input wave-form and co-ordinate system eliminates errors due to non-linearity and distortion.

Accuracy of signal plotting is claimed to be within 0·2%. The basic unit is standardized to provide full scale deflexion for $\pm$100V and a pre-amplifier allows expansion and zero-shifting of small signals. Display periods range from 25ms to 50s; input signals and voltages for producing the co-ordinate lines are sampled every 62·5μs for display.

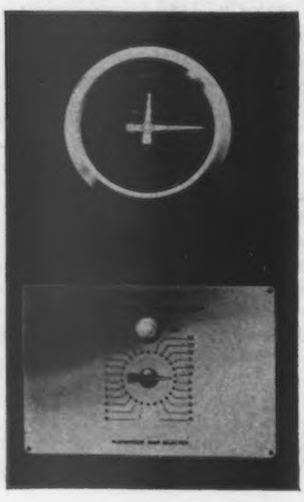
Circle **No 582** on reply card

REMOTE LEVEL INDICATOR

synchro transmission

Whessoe's Double Synchro 50 system uses two transmitter synchros geared together to form a coarse/fine system, the fine synchros being connected to a sprocket in the gauge head which is actuated by a perforated stainless steel tape connected to a float in the tank. The transmitter synchros are electrically connected to the corresponding synchros in the repeater. Any change in level makes the sprocket rotate, so altering the angular position of the repeater synchros, and of the two pointers on the dial indicator. The coarse pointer indicates feet, and the fine pointer subdivides this reading to an overall accuracy of $\frac{1}{32}$in. A single synchro

Fine and coarse indication



system is also available, which is intended for operations where great accuracy is unnecessary.

Circle **No 581** on reply card

WEIGHT TRIP-AMPLIFIER

accurate, transistorized

The Ekco N684 weight trip-amplifier is a 12V transistorized unit which operates an alarm on weight-overloading or circuit failure. Two systems are available: one lights an amber lamp at the preset safe load, and provides two further signals at a predetermined percentage deviation below and above safe load respectively. The second system lights a red lamp when the safe-load limit is reached, in addition to continuous meter-indication of actual safe-load percentage. Safe-load alarm accuracy is $\pm$0·5%, and deviation alarm accuracy is $\pm 2\frac{1}{2}$% of setting, over a temperature range from -10 to $+40$°C. The amplifier circuits light a red lamp if any part of the internal circuit fails, a green lamp indicating that the battery supply is connected.

Circle **No 569** on reply card

FUEL-OIL METER

accurate at low flow-rates

An oil meter by Walker Crosweller measures flow accurately down to $1\frac{1}{2}$ gal/h under heads as low as 2ft. This integrating instrument uses a nutating

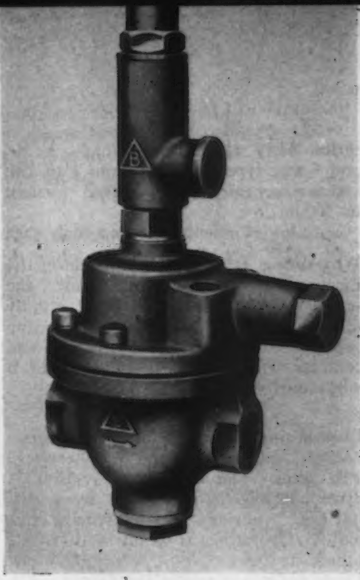
Accurate, sensitive

piston principle—flat disk oscillating on its periphery—which makes for high sensitivity. Accuracy is claimed to be $\pm$1%. Circle **No 550** on reply card

PRESSURE PROTECTION VALVE

limited closure

An excess pressure protection valve for steam lines, by W. H. Bailey, does not completely shut off the system supply in an emergency, the downstream reduced pressure being maintained at the set level so that process work, etc., is not interrupted. The device includes a double-beat valve attached to a piston, across which a pressure differential will be produced by any marked increase in inlet pressure. The effect of the differential is to lift the piston, which brings the main valve closer to its seating faces, so that the downstream line is automatically protected from excess pressure. As soon as the supply pressure



150 lbf/in² working pressure

returns to normal, the valve automatically resumes its original position.

Normal working pressure of these valves is 150 lbf/in² of steam, but in emergencies the valve will tolerate an inlet pressure up to 300 lbf/in². Spring ranges available are 2–10, 10–80, and 80–150 lbf/in².

Circle **No 558** on reply card

PACKAGED COMPUTER SYSTEM

ready-to-wear

Claimed to be the first standard computer system packaged for 'off the shelf' sales to electricity generating stations, General Electric's (U.S.A.) Garde system is for monitoring, logging, and processing of steam plant operational data. The heart of the system is the G.E. transistorized 312 digital process-control computer. Installation time for the whole system may be as little as thirty days

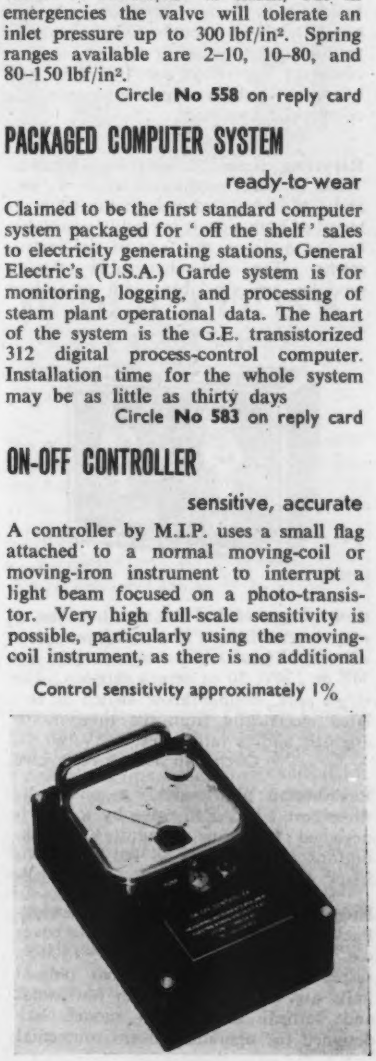
Circle **No 583** on reply card

ON-OFF CONTROLLER

sensitive, accurate

A controller by M.I.P. uses a small flag attached to a normal moving-coil or moving-iron instrument to interrupt a light beam focused on a photo-transistor. Very high full-scale sensitivity is possible, particularly using the moving-coil instrument, as there is no additional

Control sensitivity approximately 1%



load on the movement. Maximum normal sensitivity is 20μA using a 4500Ω coil; with a special magnet system, higher sensitivities are obtainable.

An isolated single-pole double-throw switch, rated 3A, 200/250V a.c., is provided, also a second circuit giving up to 3A at 200/250V a.c. for warning or control equipment working at mains voltage. Control sensitivity is approximately 1%. The unit is available as an up-sensing, down-sensing, or combined up- and down-sensing controller.

Circle **No 551** on reply card

ALTERNATING-VOLTAGE STABILIZER

1kVA output

The TS-2, by Claude Lyons, is claimed to provide rapid, accurate and distortionless stabilization over an input voltage range of 25%, with an output of about 1kVA. An alternative connexion gives an output of about 2kVA, over a 12½% input range.

This solid-state unit has a dual range 'buck and boost' transformer with two secondary windings which may be either series- or parallel-connected. With either

Correction speed 40V/s

connexion, three input ranges are available: −17½ to +7½%, ±12½%, and −7½ to +12½%. When parallel connected, the correction range is halved, but the power output is doubled. Correction speed is 40 V/s, and accuracy is given as ±0·5%, zero to full load at any power factor. Supply frequency may be from 47–65 c/s. The illustration shows model TS-2; model TS-2R is electrically identical, but is made for panel mounting in a standard 19in rack.

Circle **No 579** on reply card

PROFILING AND MILLING MACHINE

numerical control

Numerically controlled profiling and milling machines by Ekstrom–Carlson (U.S.A.) are available in the U.K. from Gaston Marbaix. The 200 series is a three-spindle, three-dimension machine, with a table 60in wide by 96in long. Movements are as follows: transverse (of head), 32in; longitudinal, 100in; vertical slide, 10in. Each axis of motion is driven by a recirculating anti-backlash ball-bearing screw, having a non-cumulative lead-error of 0·0005 in/ft.

Either punched tape or magnetic tape control systems can be supplied as required, and complete manual control is provided in all cases. In standard systems, spindle speed is 'dial-controlled' by the operator; an optional feature is available by which spindle speeds may be programmed into the tape.

Circle **No 577** on reply card

ROTARY ACTUATOR

pneumatic operation

A pneumatically operated actuator by N.S.F. uses a system of balls running in inclined races to convert linear into rotary motion. At maximum operating pressure, 120 lbf/in², torque output

Uniform torque

is 6·5 lbf in for 90° output-shaft rotation. Torque is uniform throughout the rotary stroke, so avoiding the need for compensation. Under no-load conditions, a 90° stroke takes 30–40ms at 120 lbf/in². Air displacement of the series 50 is 0·16in³, and the piston stroke is 0·078. The unit weighs eight ounces. The range of models will shortly be extended to cover torque outputs from 1·35 lbf in to 94 lbf in. (The operation of this device is more fully explained in *Ideas applied*, in this issue.)

Circle **No 571** on reply card

PUNCHED TAPE VERIFIER

5-, 6-, or 7-track tape

Made by Creed for data processing applications, the model 90 automatically detects and eliminates operator errors in punching 5-, 6-, or 7-track tapes at speeds up to 15 characters/s.

The verifier automatically compares two separate transcriptions of the same source data. The unverified tape is fed into the tape reader, and the data are typed a second time from the source document. The units are electrically interconnected in such a way that when the code produced by the second typing agrees with that already punched in the original tape, the same character is punched in a second tape. When the two codes do not agree, the keyboard locks and nothing is punched on the second

Automatic verification

tape. The operator determines in which typing the error has occurred, and punches the correct character in the second (verified) tape. Another version incorporates the Creed. model 75 teleprinter with tape-punch attachment, so extending the scope of the equipment to include page-printing and tape-editing and interpreting facilities.

Circle **No 556** on reply card

ELECTRONIC VOLTMETER

wide frequency-range

The model 317 voltmeter, made by Ballantine Laboratories (U.S.A.), measures 300 μV to 300 V at frequencies from 10 c/s to 11 Mc/s. It may be used as a null-detector from 5 c/s to 30 Mc/s. As a calibrated amplifier it has a gain up to 60 dB, with a frequency response $\pm$ 1 dB from 6 c/s to 11 Mc/s. The 5 in meter-scale is mirror backed, and is calibrated in volts and decibels. Input impedance with probe is 10 MΩ shunted by 5 pF. Without probe it is 2MΩ shunted by 11–24 pF.

Circle **No 553** on reply card

PORTABLE OSCILLOSCOPE

wide band-width

Made by Telequipment, the S32 weighs only sixteen pounds. A high-voltage c.r.t. is used, which is claimed to give a very fast rise-time. Band-width, with a sensitivity of 100mV/cm, is d.c. to 7·5 Mc/s; a high-gain position is also provided, with a sensitivity of 10mV/cm from d.c. to 200 kc/s. The unit operates from 110V or 200–250V a.c. supplies.

Circle **No 554** on reply card

QUICK LOOKS

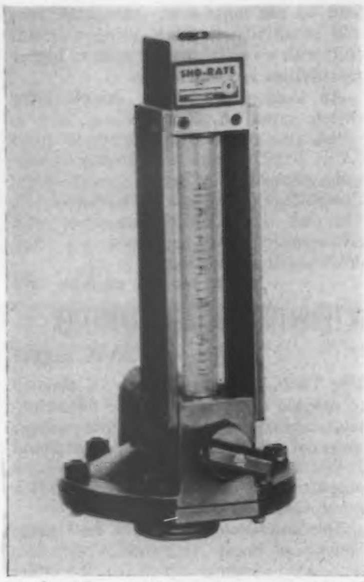
Chain drives. An extension to the range made by Renold, a new series uses a 0·625in pitch roller-chain, and so provides a step between 0·5 and 0·75in pitch simple-chain drives. Twenty-one different ratios are available, with four alternative modes of lubrication. The drives may be run at pinion speeds up to 2200 rev/min, transmitting 16 hp at this figure.

Circle **No 575** on reply card

Transistor oscillators. The TG 150D and TG 150DM, by Levell Electronics, provide sine- and square-wave outputs over the frequency range 1·5 c/s to 150 kc/s. Square-wave output is continuously variable up to 2·5V peak at a source impedance rising from zero to 600Ω at maximum output. Rise time: the time from 10% to 90% points is approximately 1% of the periodic time plus 0·2μs. Models TG 150 and TG 150M, from which these were developed, were described in *Control*, Sept 1960, p. 134.

Circle **No 576** on reply card

Flow controllers. Brook Instrument's Series 8800 flow controllers cover a water-flow range from 3 gal/min (model 8810) to 24 gal/min (model 8800), or 12 ft^3/min to 90 ft^3/min air-flow. They may be made from brass or stainless



steel, with a maximum pressure rating of 500 lbf/in^2. (A description of the operation of these controllers may be found in *Ideas applied*, p. 115, *Control*, August 1961.) Circle **No 578** on reply card

On–off controller. A transistorized meter/controller by Farnell Instruments, the Hilo-meter, is capable of switching 0·25A at 250V a.c. Current between the meter pointer and contact arms is less than 1mA. The basic instrument has an accuracy of 1% full scale, and repeatability is also claimed to be 1%.

Circle **No 573** on reply card

Toroidal primary transformer. A device by Farnell Instruments consists of a toroidally-wound primary winding, so arranged that secondary windings may be wound on to it easily and quickly. The primary winding is rated at 250VA continuous or 350VA intermittent, 220/250V, 50–60c/s. In addition to providing low-voltage a.c. (at mains input each secondary turn gives 0·33V), it may be used in reverse as a current transformer. Circle **No 574** on reply card

Stop valves. Simplifix type 60 valves are now available in the following sizes: $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1 in B.S.P. female. All valves are made from gunmetal to resist corrosion, the spindles are manganese bronze, and valve tips are nylon. Maximum working pressures range from 1000 lbf/in^2 hydraulic, 200 lbf/in^2 gases, for the $\frac{1}{4}$in valves, to 250 lbf/in^2 hydraulic to 100 lbf/in^2 gases for the 1 in valve.

Circle **No 561** on reply card

Adjustable pot-cores. Available from Plessey, Ferramic T pot-cores have diameters of 14, 18, 22 and 26mm; with standard effective permeability values of 63, 100, 160 and 220. A frequency spectrum from 1 kc/s to 1 Mc/s may be covered. Circle **No 562** on reply card

Control valves. A range of manifold mounted valves is introduced by British Arca to supplement their side-ported series. They are available in 2-, 3-, 4-, and 5-way types, in sizes from $\frac{1}{4}$ to 1in, and for pressures from partial vacuum to 500 lbf/in^2.

Circle **No 563** on reply card

Wire-spring relay. Made by Automatic Electric Industrial (Switzerland), the series WQA relays are designed rapidly to transfer up to 51 circuits. Operating voltages range from 6V to 22V d.c. and contacts will carry 3A, 150W, with a non-inductive load.

Circle **No 564** on reply card

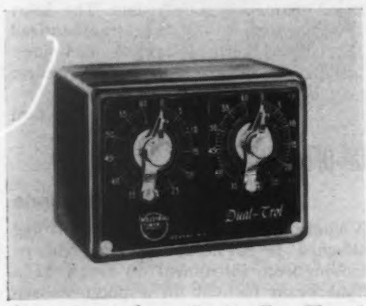
Elapsed-time meter. Units by English Electric will register up to 9999·9h in 0·1h steps. The cyclometer register is driven, through a gear-chain, by a self-starting, non-reversing synchronous motor. Operation is from a 50–60 c/s supply, at 100–125, 200–250, or 400–440V. Three types are made: the H21M, in a 4in square, flush mounting, switchboard-pattern case; and the S25 ($2\frac{1}{2}$in) and S35 ($3\frac{1}{2}$in), for panel mounting.

Circle **No 555** on reply card

Relay. B & R Relay's type B.04 may be fitted with one normally-open or normally-closed vacuum switch, with up to three make, break, or change-over B.0. contacts. The relays are $4\frac{1}{2}$in long, and up to $3\frac{1}{2}$in high depending upon the contract arrangement.

Circle **No 557** on reply card

Recycling timer. A unit by Industrial Timer (U.S.A.) produces a series of 'on' and 'off' electrical pulses; the time interval of both signals is readily adjustable by the dials on the face of the instruments. Ten interchangeable timing modules are available, with maximum



time ranges from 6s to 3h. The 6 module can be set to a minimum time of $\frac{1}{10}$s. These units are operable on 115 or 230V, 50 or 60 c/s supplies. The single-pole, double-throw switch is isolated electrically from the timer-motor circuits, and is rated 10A, 115V, 60 c/s.

Circle **No 568** on reply card

Push-button pilot valve. A pneumatic three-port $\frac{1}{8}$ in B.S.P. valve by R.G.S. is designed for panel mounting. Push-buttons are available in red, green, or black. Circle **No 559** on reply card

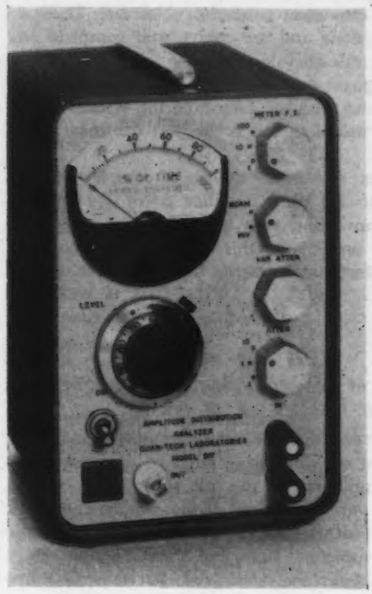
Rugged oscilloscopes. Made by Hewlett-Packard (U.S.A.), two oscilloscopes cover d.c. to 30 Mc/s and d.c. to 15 Mc/s respectively. A feature is that plug-in units are available for both horizontal and vertical axes. Both models are designed for operation in environmental

New for the user

conditions, such as in M.I.L. vigration and shock tests, at temperatures up to 50°C, humidities up to 95%, and altitudes up to 10,000ft.

Circle **No 572** on reply card

Noise analyser. A compact amplitude-distribution analyser, Model 317, by Quan-Tach (U.S.A.), indicates the amplitude-probability distribution of



random signals. A voltage threshold-level is set by a front-panel control: noise-levels exceeding the preset voltage level are indicated on a scale calibrated in percentage referred to time. This transistorized unit operates at switching rates up to 5 Mc/s. Amplitude ranges are 100%, 10% and 1% full scale, and accuracy is given as ±3% full scale.

Circle **No 580** on reply card

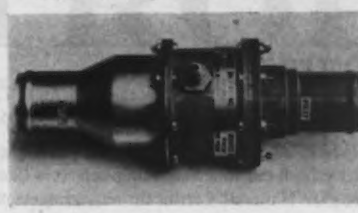
Process timers. Units by Richard Allan are available covering the following ranges: PT1L, 0·1–5s; PT1, 1–55s; PT1H, 1–55s, plus five switched intervals of 50s, *i.e.* 305s total. Repetitive accuracy is given as ±1%, and setting accuracy remains within 5% over a range of mains voltages from 200 to 250V a.c. Contacts are rated at 5A, 250V.

Circle **No 565** on reply card

Time/temperature indicator. A miniature integrator, weighing less than one ounce, is available from Honeywell. It is used to check that frozen food, in storage and transit, does not rise above 0°F for too long a period. It acts like a small electric battery, and senses and records time and temperature as an integral function, the combined information being shown on a tiny scale.

Circle **No 552** on reply card

Vent valve. A dual inward/outward vent valve, the R.V. 63, is available from Hymatic for use in the pressure control of tanks in fuel systems. It is fully compatible with fuel. During inward venting, the valve passes 20 ft³/min with a pressure drop of 0·3 lbf/in² in ground level conditions. The outward relief vent has a nominal blow-off pressure of 3 lbf/in², and 6 ft³/min air flow at 3·4 lbf/in² back pressure. With the out-



ward relief vent held open during re-fuelling it will pass 35 gal/min with a minimum fuel servo pressure of 26 lbf/in². Circle **No 560** on reply card

Miniature Relay. The Microtact, by Leland Instruments, is an hermetically-sealed moving-coil measuring relay. Three windings are available; 2500, 125, and 2·5Ω; deflexion sensitivities (full scale) are respectively 50μA, 250μA, and 2·5mA. In each case the relays may have centre zero, or a conventional maximum/minimum arrangement. In the latter case, when no current is flowing the moving contact rests at the 'minimum' position. Response time, depending on the particular model and the contact settings, is 0·1 to 0·5s. The contacts will handle 30mW at a maximum of 20V a.c. or d.c.

Circle **No 567** on reply card

PUBLICATIONS RECEIVED

The mechanics of inertial position and heading indicators *by* **Winston Markey** *and* **John Hovorka.** *Methuen. 1961. 94 pp. £1 1s.* ★ **585**

Electronics: a bibliographical guide *by* **C. K. Moore** *and* **K. J. Spencer.** *Macdonald 1961. 411 pp. £3 5s.* ★ **586**

Electronic Computer Exhibition. Details of this exhibition are given in five languages in a 16-page booklet from Pritchard, Wood, and Partners. ★ **590**

'Regional Development Plan for Courses for the Diploma in Technology'. A booklet from the London and Home Counties Regional Advisory Council for Technological Education, describing various courses available. ★ **591**

Openside profiling and milling machines by Ekstrom, Carlson (U.S.A.) are the subject of Bulletin No. 210 from Marbaix. ★ **592**

'High purity CO_2 from waste flue gases' is the title of a reprint from Incandescent Heat. ★ **593**

Electric lifting magnets by G.E.C. are listed in a revised brochure No. P. 1008. ★ **594**

Dust meter. James Gordon's 'Konitest' dust meter is described in catalogue No. 170. ★ **595**

'Statistical Review of the World Oil Industry, 1960'. Information on all aspects of the industry, compiled by British Petroleum in a 24-page booklet. ★ **596**

Aircraft electrical equipment by Plessey is detailed in a 28-page illustrated booklet (Publication No. 308). ★ **597**

'Worldwide Service to Industry'. An industrial leaflet describing what Plenty do. ★ **598**

Dial assemblies for the angular positioning of synchros, resolvers, etc., are the subject of a technical bulletin from Theta (U.S.A.). ★ **599**

Flame failure equipment. Data sheets FS issue 3 and FSF3 issue 1 from Elcontrol describe respectively their improved FSM range, and a flame failure unit for oil-burners. ★ **600**

Magnetic separators, by G.E.C.'s Witton-Kramer Div., are shown in Technical Description No. 315. ★ **601**

'Radio research 1960', from D.S.I.R., is the report of the Radio Research Board and the report of the Director of Radio Research. ★ **602**

Precision wirewound resistors are listed in Ashburton's 16-page Arcol catalogue. ★ **603**

Photo-electric counters. Tyer's Parram transistorized counters are described in their recent leaflet. ★ **604**

Controller. Cambridge Instrument's indicating pneumatic temperature controller is the subject of their leaflet list 103. ★ **605**

'Automation and process control' is the title of an 8-page booklet detailing the activities of Automatic Control Engineering. ★ **606**

Motors. Totally enclosed fan-cooled cage-rotor motors manufactured to British Standards, are described in leaflet SL.2 from Lancashire Dynamo and Crypto. ★ **607**

Magnetometer. Griffin's Varicoil laboratory magnetometer, for educational use, is described in a recent leaflet. ★ **608**

Numerical keyboards, VE874 and 871, for use with data processing and data analysis systems, are described in a leaflet from Ultra Electronics. ★ **609**

'Contact fingering' is the title of a leaflet from Sealectro. ★ **610**

★ **Circle the relevant number on the reply card facing page 162 for further information**

Book Reviews

Servo-mechanisms

An introduction to servomechanisms *by* **F. L. Westwater** *and* **W. A. Waddell.** *English Universities Press Ltd. 1961. 191 pp. 15s.*

This is an elementary textbook where the essential mathematics have been cut to a bare minimum. It is intended basically to cover Higher National Certificate requirements, but the mathematics is not of a higher standard than O.N.C. The first five chapters introduce the subject and deal with the essential mathematics, the emphasis being on the characteristics of a second-order linear differential equation with constant coefficients. The introduction of sinusoidal analysis is also included.

Part II of the book deals with the theory of simple feedback systems from a frequency response approach, dealing with transfer functions and their manipulation, an approach to the Nyquist criterion, gain and phase margins, and examples of stabilization of servo-mechanisms. The use of logarithmic plots is introduced and a final chapter gives a simple description of servo-mechanism components.

The authors are to be congratulated on having covered so much of servo-mechanisms theory whilst maintaining an elementary standard. However, simplification inevitably produces statements which are dubious. Whilst talking about lags in systems, the authors say 'it is a matter of great difficulty to measure the input and output at the same time'; this is demonstrably untrue. The definition of a vector, while satisfactory for the context of the book, is completely incorrect, and in one place the word 'complex' is used to mean an imaginary component. The book is marred by the rather loose classroom language; there is a 'catch' in solving differential equations, and there are various 'ills' to which a simple servo-mechanism is a 'prey'. JOHN C. WEST

Filters

Statistical theory of communication *by* **Y. W. Lee.** *John Wiley & Sons Ltd. 1960. 509 pp. £6 14s.*

This book is a very complete exposition of Wiener's filter theory. The author explains in his introduction that the book is based on a course which he first gave at M.I.T. in 1947. As one of his grateful students on that occasion I find it a pleasure to be reviewing his book. Some slightly aging seers of an almost bygone age will recall the original Wiener Yellow Peril; the restricted document with ochre covers which might just as well have been written in Chinese as far as most of us were concerned (and perhaps after all was!). Only those few whose business it was to try and understand the original will realize quite how grateful we should be to Professor Lee for his valiant service between Norbert Wiener's genius and more humble comprehensions. The lectures are now recorded more permanently (and with considerably broader scope of material, comparing the present volume with the notes from the inaugural presentation), but still there comes through in the pages the quite characteristically pithy style of the author.

The Wiener filter theory represents an important extension of the power of operational methods to allow their use in connexion with some statistical functions. It uses the mean square error as the criterion, and finds, by a variational method, that linear filter which yields a minimum of this measure in filtering statistically a known message from the mixture of message and disturbance. An important result that emerges is that filtering improves if a time delay can be allowed, but that such improvement does not go on indefinitely as time delay increases; there is finally an irreducible error. The book deals very fully with all these matters and with the background material that leads up to it. One feels more clearly about the book what one felt slightly about the course, namely that this leading-up-to-things has been taken a bit far: probability has been heard of by the time one wishes to understand Wiener! We do not get to grips with the Wiener method properly until p. 335 in the book, then in the span of a further 83 pages we have the essence of the matter in all necessary detail, including the important treatment of errors. These 83 pages are very well done and are pretty well complete and self-contained, but in this encyclopaedia age we do not get off without a full 500 pages including the supporting material. However, for those who wish to understand the Wiener theory and make intelligent use of it, this is the best treatment available.

Two small grumbles; one regrets the use of complex variable $j\lambda$ instead of the (to us) more familiar p (or s), and also Wiener's arbitrary convention with his 2π's. One minor mistake in equation 29 on p. 401; this has a surplus constant factor k_1^2 which unfortunately carries on throughout the remainder of the book. J. H. WESTCOTT

Analogues

Design fundamentals of analog computer components *by* **R. M. Howe.** *Van Nostrand. 1961. 268 pp. £2 16s. 6d.*

This book is a most worth-while addition to the small, but nevertheless at present ever-increasing range of textbook literature on analogue computers. As the title suggests, the subject matter deals with the various portions of the complete analogue computer installation, rather than the application of the whole to the solution of problems. Here and there, to illustrate a particular point, problems are considered, but these are few and far between and of a simple nature.

Aspiring analogue computer engineers should find this book a boon, as it deals in detail with all the various aspects of accepted design and construction—in the American field, of course. Various manufacturers' products are considered, and one marvels at the common denominator which is clearly apparent at this present (can one say, late?) stage of evolution. Here obviously is a field in which the Americans lead the world so far as the custom-built analogue computer is concerned. When one reads of the setting of coefficient potentiometers by means of push-button-controlled servo-mechanisms one begins to wonder if the slight discrepancy between the English and American spelling is not after all simply a language consideration. F. WALKER

Miniatures

British miniature electronic components and assemblies data annual 1961–62 *edited by* **G. W. A. Dummer** *and* **J. Mackenzie Robertson.** *Pergamon Press. 1961. 479 pp. £4.*

To the reader who knows the series of books on components by Mr Dummer, this volume may come as a disappointment. It is largely a collection of manufacturers' leaflets and specifications, slightly edited and photographically reproduced. It details some 150 items which are either smaller than a one-inch cube or are the smallest of their kind. There is a good index and eighteen pages of advertisements.

It is debatable whether a design engineer, who receives most of the information directly from manufacturers by post or at exhibitions, will welcome such an assembly at the price. However, it is an excursion into a fast-growing jungle, to be repeated annually. At present it deals mainly with components; if later volumes will concentrate on the less-publicized assemblies, the value of the series will be enhanced. R. J. REDDING